

Environmental Studies No. 28

Climate of Northwestern Baffin Bay and Lancaster Sound

Northern Affairs Program

D.B. Fraser

Published under the authority of the
Hon. John C. Munro, P.C., M.P.,
Minister of Indian Affairs and
Northern Development,
Ottawa, 1983.

QS-8323-000-EEAI
Catalogue No. R71-19/29-1983E
ISBN 0-662-12409-X

Cette publication peut aussi être obtenue en français.

Minister of Supply and Services Canada

This report was prepared under contract for Petro-Canada as part of the Eastern Arctic Marine Environmental Studies (EAMES) program. The views, conclusions and recommendations expressed herein are those of the author and not necessarily those of Petro-Canada or the Department,

A Canadian contribution to the Unesco Program on Man and the Biosphere (MAB).

Climate of Northwestern British Columbia and Vancouver Island

Northwest Atlantic Project

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Received for publication
October 10, 1978

Accepted for publication
November 1, 1978

Journal of Ecology and Environmental Science

This report was prepared under contract for the
Government of British Columbia. The work was
done in the Department of Geography, University of
British Columbia, Vancouver, B.C.

A complete bibliography is included in the
appendix.

ACKNOWLEDGEMENTS

The author wishes to thank the following:

Mr. B. Janz made a number of positive suggestions in reviews of interim reports of this work.

Mr. W.C. Thompson established the terms of reference and provided constructive criticism of this work.

Mr. H.P. Wilson suggested certain reference materials relevant to the study region.

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	v
LIST OF TABLES	viii
EXECUTIVE SUMMARY	1
FORWORD	2
1.0 INTRODUCTION	3
2.0 STUDY AREA	7
2.1 Location	7
2.2 Physical Description	7
2.2.1 Topography	7
2.2.2 Sea Surface	7
3.0 DATA SOURCES AND ANALYSES	10
3.1 Observed Data	10
3.1.1 Marine Observations	10
3.1.2 Data from Land Stations	14
3.1.3 Petro-Canada Observations	14
3.1.4 Other Observations	14
3.2 Synthetic Data	15
3.3 Evaluation of Data Sources	15
3.3.1 Marine Observations	15
3.3.2 Land Stations	16
3.3.3 Synthetic Data	17
3.4 Analyses	16
3.4.1 Analyses of Normal Climate	17
3.4.1.1 Method of Maxwell	17
3.4.1.2 Method of Duck	17
3.4.1.3 Method of Thomson and Vickers	18
3.4.1.4 Method of Lachapelle	18
3.4.1.5 Other Studies	19
4.0 CLIMATIC CONTROLS	20
4.1 Radiation	20
4.2 Atmospheric Circulation	20
4.3 Topographic Effects	20
4.4 Effects of Underlying Surface	22

	<u>Page</u>
5.0 PRESSURE AND WIND	23
5.1 Pressure	23
5.1.1 Pressure-Wind Relationship	23
5.1.2 Mean Pressure	23
5.2 Wind Direction	24
5.3 Wind Speed	35
5.4 Duration of Winds	37
5.5 Extreme Winds	38
6.0 AIR TEMPERATURE	42
6.1 Mean Air Temperature	42
6.2 Extreme Air Temperatures	42
6.3 Wind-Chill	46
7.0 SEA STATE	52
7.1 Wind Waves	52
7.1.1 Maxwell's Analysis	52
7.1.2 Duck's Analysis	52
7.1.3 Thomson-Vickers Analysis	52
7.1.4 Lachapelle (1980)	52
7.1.5 Discussion	55
7.2 Swell Waves	56
8.0 STRUCTURAL ICING	57
8.1 Procedure	57
8.2 Discussion	57
9.0 CLOUDS, CEILING AND VISIBILITY, AIRCRAFT ICING AND PRECIPITATION	62
9.1 Cloud	62
9.2 Ceilings and Visibility	63
9.3 Aircraft Icing	64
9.4 Precipitation	69
10.0 SYNOPTIC CLIMATOLOGY AND EXTREME STORMS	71
10.1 Synoptic Climatology	71
10.2 Storm Types	73
10.2.1 Type A Storms	73
10.2.2 Type B Storms	77
10.2.3 Type C Storms	77
10.2.4 Type D Storms	77
10.3 Frequency	84

	<u>Page</u>
10.4 Extreme Storms	
10.4.1 Extreme Storm 23-25 November, 1976, (Type A & D)	85
10.4.1.1 Meteorological Extremes	86
10.4.2 Extreme Storm 25-27 September, 1977, (Type B)	87
10.4.2.1 Meteorological Extremes	87
11.0 POTENTIAL FOR AIR POLLUTION AND CLIMATIC CHANGE	88
11.1 Air Pollution Potential	88
11.2 Climatic Change	88
12.0 REFERENCE CITED	90

LIST OF FIGURES

	<u>Page</u>
1.1 Study area; proposed drill sites, topography and reference points	4
2.1 Study areas and reference points of meteorological studies of Baffin Bay and Lancaster Sound	6
2.2 Mean monthly extent of North Water	8
3.1 Short term observing stations	11
4.1 Mean daily radiation values observed at Resolute A (1970-1976)	21
5.1 Mean sea level pressure and wind roses for January	25
5.2 Mean sea level pressure and wind roses for April	26
5.3 Mean sea level pressure, wind roses and prevailing winds for July	27
5.4 Mean sea level pressure, wind roses and prevailing winds for August	28
5.5 Mean sea level pressure, wind roses and prevailing winds for September	29
5.6 Mean sea level pressure, wind roses and prevailing winds for October	30
5.7 Wind roses for marine and land locations for August	31
5.8 Wind roses for marine and land locations for September	32
5.9 Percentage exceedance of wind speed for marine grid points 11 and 12, reference point A and Resolute for August	33

	<u>Page</u>
5.10 Percentage exceedance of wind speed for marine grid points 11 and 12, reference point A and Resolute for September	34
5.11 Estimated design wind speeds for the July-to-October period in northwestern Baffin Bay	40
5.12 Estimated design wind speeds for the July-to-October period in Lancaster Sound	41
6.1 Mean daily temperatures in January	43
6.2 Mean daily temperatures in May	43
6.3 Mean daily temperatures in July	44
6.4 Mean daily temperatures in August	44
6.5 Mean daily temperatures in September	45
6.6 Mean daily temperatures in October	45
6.7 Expected extreme minimum temperatures for various return periods for Resolute A	47
6.8 Wind-chill comfort classes based on combined wind-temperature effects	48
7.1 Percentage frequency of occurrence of observed wave heights for marine areas for August and September	53
7.2 Expected extreme significant wave height for northwestern Baffin Bay and Lancaster Sound	54
8.1 Conditions for sea spray icing	58
8.2 Expected extreme structural icing events for northwestern Baffin Bay	59
9.1 Annual mean total precipitation	70

	<u>Page</u>
10.1 Storm track corridors affecting Baffin Bay and Lancaster Sound	72
10.2 Mean sea level pressure pattern for 1200 GMT, 23 November 1976, showing a Type A storm development	74
10.3 50 kPa contour pattern for 1200 GMT, 21 August 1978, associated with a Type A storm development	75
10.4 Mean sea level pressure pattern for 1800 GMT, 21 August 1978, showing a Type A storm in Baffin Bay	76
10.5 50 kPa contour pattern for 0000 GMT, 25 September 1974, associated with a Type B storm development	78
10.6 Mean sea level pressure pattern for 0000 GMT, 26 September 1974, showing a Type B storm centre over Boothia Peninsula	79
10.7 50 kPa contour pattern for 0000 GMT, 18 September 1978, associated with a Type C storm	80
10.8 Mean sea level pressure pattern for 0000 GMT, 18 September 1978, showing a Type C storm	81
10.9 50 kPa contour pattern for 1200 GMT, 23 November 1976, associated with a Type D storm development	82
10.10 Mean sea level pressure pattern for 1800 GMT, 24 November 1976, showing a Type D storm centre in Baffin Bay	83

LIST OF TABLES

	<u>Page</u>
3.1 Meteorological data available from study area	12
5.1 Number of duration events longer than 24 h and maximum duration length for three wind-speed classes	39
6.1 Summary of monthly mean and extreme temperature values	49
6.2 Percentage frequency of occurrence of temperature classes during the period of record for marine grid area #11	50
6.3 Percentage frequency of occurrence of temperature classes during the period of record for marine grid area #12	50
6.4 Percentage frequency of occurrence of temperature classes during the period 1957-1966 for Resolute A	51
6.5 Percentage frequency of occurrence of wind-chill comfort classes	51
7.1 Significant wave heights computed by Duck, Lachapelle, Thomson and Vickers and observed values in northwestern Baffin Bay	55
8.1 Severe structural icing in northwestern Baffin Bay	60
9.1 Mean monthly total cloud amounts	63
9.2 Relationship of visibility and wind speed in marine grid areas	65
9.3 Percentage frequency of occurrence of combined ceiling and visibility classes for the marine grid areas	66

	<u>Page</u>
9.4 Percentage frequency of occurrence of combined ceiling and visibility classes for Resolute A	67
9.5 Probability of aircraft icing over the northwestern Baffin Bay area	68
10.1 Frequency, intensity and duration of storm types in the 1969-79 period	84
10.2 Comparison of estimated extreme storm conditions in northwestern Baffin Bay with other regions	85

- * Reference points and sites in tables and figures are not necessarily official names, part may be derived from local usage.

1941

The first of the year was a very busy one for the
company. The new product was introduced and the
sales were very good. The company was very
successful in the first quarter of the year.
The second quarter was also very successful.
The company was able to increase its sales
and its profits. The third quarter was also
very successful. The company was able to
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EXECUTIVE SUMMARY

Western Baffin Bay - Lancaster Sound is a relatively homogeneous climatic region. The climatic controls have similar effects in various sectors and the region is influenced by the same types of synoptic scale storms. Average temperatures and mean annual precipitation decrease westward across the region.

The area studied in northwestern Baffin Bay is not significantly stormy during July to November. An investigation of storms that occurred over an 11-year period indicates that less than one storm with gale force winds occurred in the July-August period per season. One storm per season occurred in September, and two or three occurred per year in each of the months of October and November.

Storms affecting the region two to four weeks prior to freeze-up (mid-October) are the most severe of the navigation season.

Over a 25-year return period, the maximum hourly wind speed in northwestern Baffin Bay is estimated to be 106 km/h and the corresponding significant wave height 8.4m. Respective values in Lancaster Sound are 109 km/h and 5.8m; the waves are lower here than in northwestern Baffin Bay because land masses restrict the fetch. Comparable values in the Beaufort Sea are 113 km/h and 6.5 m.

Potential extreme ice accretion rates are 13 and 19 cm/24h in Lancaster Sound and northwestern Baffin Bay, respectively, compared to 28 to 39 cm/24h over the Beaufort Sea.

Significant wind directions are from the northwest or southeast in northwestern Baffin Bay, and from the east or west in Lancaster Sound. Winds tend to parallel the coastlines close to shore.

Storms move into the region from the south or west, where there is an existing network of synoptic stations. There are no blind sides (large areas without reporting stations "upstream" along primary storm tracks) to hinder prediction, as in the Beaufort Sea and southern Davis Strait. The existing synoptic network could be supplemented with land-based automatic weather stations to enhance prediction.

FOREWORD

This report describes the climate and related environmental factors of northwestern Baffin Bay and eastern Lancaster Sound. It is one of five integrated reports produced under the EAMES northern program which was initiated to gather information to support an EIS for exploratory drilling.

A detailed study of the climate of northwestern Baffin Bay for the July to November period was undertaken by the Arctic Meteorology Section, Atmospheric Environment Service (AES) under contract to Petro-Canada. That study commenced in 1978 and appeared as an unpublished manuscript entitled "The Climate of Northwestern Baffin Bay" by Maxwell, Duck, Thomson and Vickers (1980). During the preparation of that study, other studies were being undertaken to provide additional information. Most notable of these was the work of Lachapelle (1980) and in-house analyses of field data prepared by Petro-Canada.

In this report the author, under contract to Petro Canada has examined other published and unpublished meteorological studies of the region. Thereby combining the findings of the most recent studies with those previously presented by the Atmospheric Environment Service.

The emphasis and content of this report, in part, reflect the author's 25-year involvement in the field of operational meteorology in the Canadian Arctic.

1.0 INTRODUCTION

This report summarizes all recent studies of the climate of Lancaster Sound and northwestern Baffin Bay (Fig 1.1). It is one of five environmental study reports that summarize the oceanography, ice environment, climate, geomorphology and biology information collected during the Eastern Arctic Environmental Studies (E.A.M.E.S.) program. The Northern EMES program was initiated by the department of Indian Affairs and Northern Development and Petro Canada to prepare an application for exploratory drilling.

This report stresses the study of wind, waves, temperatures, wind-chill, super structure icing and severe storms. Other elements discussed include clouds and precipitation, ceilings and visibilities, aircraft icing, air pollution and climatic change.

The unpublished manuscript by Maxwell et al. consists of three sections. The first two describe the normal climate of northwestern Baffin Bay during July to November, and estimate extreme conditions of winds, waves, and structural icing. The reference area and point for which the extreme conditions apply are shown in Figure 1.1. The third part is an evaluation of extreme storm conditions possible, based on a study of storms that occurred during July to November of 1974-78 inclusive. Maxwell et al. is the first detailed study of the area and the main reference in this report.

Although long-term meteorological data sources are scarce in the area, meaningful statistical analyses were carried out. The criteria and method for these are described in Appendix A of Maxwell et al. (1980).

Thomson and Vickers (1980) subsequently extended their work, which was previously the third part of Maxwell et al., to cover storm conditions over an 11-year period 1969-79.



Proposed drill sites : 1 Philpots, 2 Bylot, 3 Jamestown, 4 Byam Martin
 Reference area and a reference point after Maxwell et al. (1980)
 Reference point after Duck et al. (1977).

Figure 1.1. Study area, proposed drill sites, topography and reference points.

Lancaster Sound has received considerable attention recently. Duck et al. (1977) prepared an analysis of extreme winds, waves and structural icing. The reference point to which these results apply is shown in Figure 1.1. Also, Maxwell (1980) described the climate of the region in considerable detail. Milne and Smiley (1978) examined numerous environmental aspects of drilling in Lancaster Sound.

Other studies by Lachapelle (1980), Maxwell (1980), Thompson (1980), Headley (1979a, 1979b), Duck (1979), and the Department of Indian and Northern Affairs; Draft Green Paper on Lancaster Sound, have been examined to ensure completeness in this report.



- 7, 10, 11, 12 and 18 Marine areas and grid points
- Lachapelle reference points
- Thomson-Vickers reference points

Figure 2.1. Study areas and reference points of meteorological studies of Baffin Bay and Lancaster Sound.

2.0 STUDY AREA

2.1 LOCATION

The general area of interest is shown in Figure 1.1. The boundaries of this area are identical to those used by Maxwell *et al.*, except that the western section of the area extends over Lancaster Sound.

Lachapelle (1980) was concerned with derived winds and waves at reference points shown in Figure 2.1, although data for the derivation included points outside the study area.

2.2 PHYSICAL DESCRIPTION

2.2.1 Topography

The climate of the offshore region is affected by the topography of the surrounding islands. Topographic contours are shown in the inset of Figure 1.1. Bylot Island and eastern Baffin Island are mountainous and partially glaciated. Elevations reach up to 1900m above sea level. Western Baffin Island is made up of the Borden and Brodeur peninsulas, which are essentially plateaus, each with large areas above 330 m elevation. The maximum elevation on Devon Island is near 2000 m on the ice cap over the eastern section; to the west, heights are generally from 300 to 400m. On eastern Cornwallis Island, heights rise to 300m. Local hills near Resolute rise to 150-200m, and a northwest to southeast ridge to the east of the weather station is an important feature affecting local winds.

2.2.2 Sea Surface

Detailed descriptions of the physical characteristics of Lancaster Sound and Baffin Bay are given by Marko (1982) and by Fissel *et al* (1981).

Much of Baffin Bay and Lancaster Sound are ice-covered for much of the year. Notable exceptions are the North Water and Barrow-Lancaster polynyas, where open water or light ice cover often prevails throughout the winter. The North Water has had much field study; results appear in a series of annual field reports, such as Muller *et al* (1978, 1980). Other investigators include Aber and Vowinckel (1972) and Dunbar (1969).

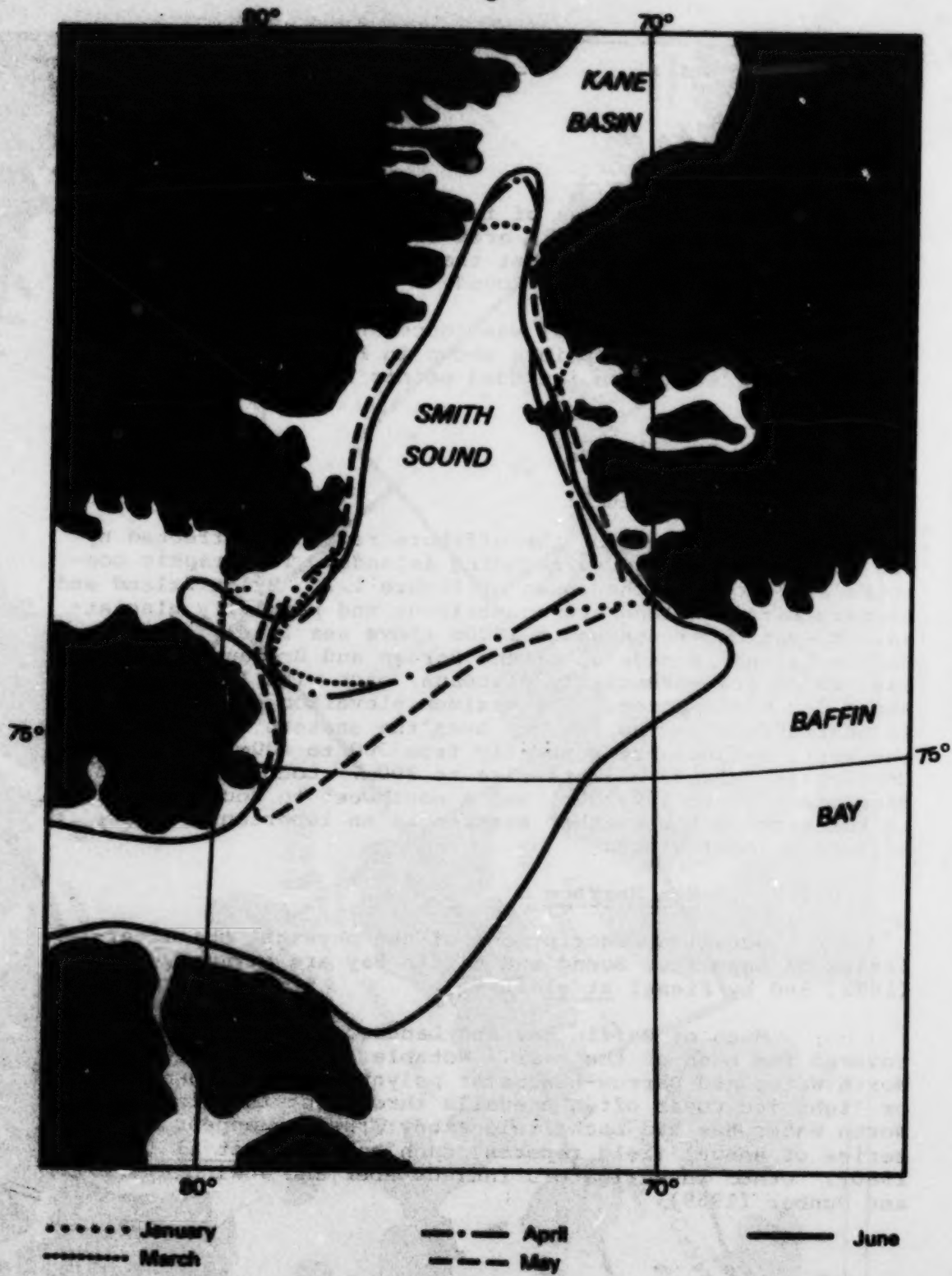


Figure 2.2 Mean monthly extent of North Water

The mean boundary of the North Water is shown in Figure 2.2, but the actual amount of open water varies considerably from year to year. The area most consistently open is the extreme northern section of Smith Sound.

Infra-red satellite imagery shows that the polynya that normally forms at the western end of Lancaster Sound and Barrow Strait has features similar to the North Water: it has open water and thin ice, downstream of a landfast or consolidated ice edge (Milne and Smiley 1978).

These two polynyas are centres for disintegration of the ice in Baffin Bay and Lancaster Sound. According to Sowden (1979), a consolidated ice edge is associated with the Lancaster Sound polynya and the position of this ice edge determines the time of break-up. The ice pack begins to loosen during May. Open water later develops along the south coast of Devon Island along the eastern edge of the fast ice. At the same time, the North Water increases in area southward, until it joins with the open water in Lancaster Sound, normally by mid-June. Afterward, there is continued melting and clearing on the south side of Lancaster Sound and an eastward movement of ice into Baffin Bay. The open area in Baffin Bay expands south and southeastward so that the study area is normally ice-free in early July.

Open water normally reaches its maximum extent in September, when the maximum fetches for wave development exist. Ice cover significant to offshore operations can begin to develop as early as mid-September and as late as the last week in October (Sowden 1979).

3.0 DATA SOURCES AND ANALYSES

The available weather data can be subdivided into two types: observed and synthetic. The observed data consist of synoptic marine observations taken from icebreakers, supply ships and other vessels in accordance with internationally accepted procedures for observing weather. A number of land-based stations also provided observed data. Most of these are located near coastlines and are listed in Table 3.1.

Maxwell *et al.* (1980) used observed data in their analyses of the climate, except for the computations of extreme values for winds and waves. For that purpose, a synthetic data set representing offshore wind was derived from observed wind data at Resolute.

Synthetic wind data were derived from grid point pressures abstracted from maps of surface pressure patterns by Lachapelle. The grid point pressures were supplied by the Fleet Numerical Oceanography Center. Thomson and Vickers used surface pressure maps provided by the Arctic Weather Centre, AES, to compute surface winds at selected points. The reference points for these calculations are shown in Figure 2.1.

3.1 OBSERVED DATA

3.1.1 Marine Observations

Approximately 8000 synoptic marine observations are available from the study area; most are from the navigation season, July to October, during the years 1947-1978.

Under international agreement, synoptic marine observations are stored at the National Climatic Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. At the request of the Atmospheric Environment Service, data for selected areas of the Canadian Arctic were analysed in the "Summary of Synoptic Meteorological Observation" (SSMO) format in 1975. Five of these marine areas that abut or overlap the study area, are represented by grid points, 7, 10, 11, 12 and 18, and are shown in Figure 2.1. The data used in these analyses, however, did not extend beyond the end of 1972. The results of these analyses were manually updated with data through to the end and used by Maxwell *et al.* (1980) and Lachapelle (1980).

Observing site	Latitude	Longitude	Elevation, m	Period of record	Nature of observing program	Operator
Arctic Bay	73 02	85 09	11	Sept. 1937- Dec. 1976	Less than 24 hour observation per day. Gaps in record.	AES
Borden Peninsula	approximately 73 35	81 30	15	July-Dec. 1978 Summer 1979	Hourly with gaps. 1979 data not examined.	Arctic Research Establishment
Cape Farnshaw	73 33	77 26	596	July-Oct. 1978	Hourly with records incomplete.	Petro-Canada
Cape Liverpool	73 40	78 07	13	Aug. 14-Sept. 29/78	Hourly	Petro-Canada
	73 39	78 00	3	July 9-Sept. 30/79		
	73 39	78 05	12	July 20-Aug. 31/80		
Cape Sheridan	74 36	80 14	1	July 7-Sept. 30/78	10-minute observa- tion interval.	Petro-Canada
	74 36	80 17	21	July 20-Oct 1/80		
Cape Charles Yorks	73 43	82 45	20	Aug. 4/77- Sept. 15/79	30-minute sampling interval.	Institute of Ocean Science
Carey Islands (GREENLAND)	76 44	73 11	10	Aug 1973-Sept. 1974	6-hourly	North Water Project
Clyde River	70 27	68 33	3	Sept. 1933- continuing	Less than hourly, gaps in record.	AES
Coburg Island	75 55	79 00	3	Sept. 1972- Sept. 1976	6-hourly	North Water Project
Craig Harbour	76 12	81 01	4	Sept. 1933- July 1940	8-hourly	RMP
Dundas Harbour	74 32	82 23	5	Sept. 1930- Aug. 1950	8-hourly with gaps in record.	RMP

...continued

Table 3.1 Meteorological data available from study area

Observing site	Latitude	Longitude	Elevation m	Period of record	Nature of observing program	Operator
Hope Monument	74 36	80 24	450	July-Oct. 1978	3-hourly	Petro-Canada
Philpots Island	74 49 74 54 74 55	79 52 79 31 79 23	12 61 10	July 11-Aug. 1, 1979 Aug. 1-Oct. 3, 1979 July 22-Oct. 1, 1980	Hourly	Petro-Canada
Pond Inlet A	72 40	78 00	59	Oct. 1921- continuing	Hourly since 1974. Gaps in previous record.	AES
Prince Leopold Island	74 01	89 58	259	July 8-Oct. 8, 1979	Hourly	Petro-Canada
Resolute A	74 41 74 43	94 55 94 59	17 64	Oct. 1947-Oct. 1953 Oct. 1953-continuing	Hourly since 1962.	AES
Thule	76 31	68 48	80	1946-continuing	Hourly since 1951	USAF
Wollaston Island	approximately 73 43	80 59	70	June-Sept. 1978 and 1979	Hourly with gaps.	Arctic Research Establishment
Marine Grid Area #7	76 30	75 00	-	Primary 1946-1978 Overall 1898-1978	July to Oct. only 1865 observations in total.	Note: Lat- tude and longitude for marine grid areas are at centre of areas.
Marine Grid Area #10	74 30	94 00	-	Primary 1947-1972 Overall 1903-1972	July-Oct. only 1902 observations in total.	
Marine Grid Area #11	74 00	85 00	-	Primary 1947-1978 Overall 1903-1978	July to Oct. 3700 observations.	
Marine Grid Area #12	74 00	75 00	-	Primary 1947-1978 Overall 1903-1978	July-Oct. 1079 observations.	
Marine Grid Area #18	71 30	70 30	-	Primary 1948-1978 Overall 1946-1978	July-Oct. 1491 observations.	

Table 3.1 (concluded)

3.1.2 Data from Land Stations

Most of the land-based stations providing data for this report were operated by or in cooperation with the Atmospheric Environment Service. The stations are listed in Table 3.1 and their location is shown in Figure 1.1. Many of these, such as Arctic Bay, Craig Harbour, Carey Islands, Coburg Island and Dundas Harbour, are no longer in operation. Resolute, Clyde River and Thule are the only stations with a long period of record. Of these, Resolute is by far the most representative, even though it is located well west of the study area and its wind regime suffers from some local effects.

3.1.3 Petro-Canada Observations

In addition to the Atmospheric Environment Service stations, Petro-Canada collected data in the study area during 1978-80. In 1978, manned radar stations to track icebergs were maintained at Cape Fanshawe and Hope Monument. Weather observations were taken at those locations as well as at Cape Liverpool and Cape Sherard by the respective contractors.

Also in 1978, an ice movement monitoring station utilizing an automatic weather station and satellite communications was developed. The resulting Self-contained Arctic Long-term Data Acquisition System (SALDAS) was first deployed in the Sverdrup Basin. In 1979, the automatic weather station was removed from the main station, and in consultation with staff in the Arctic Weather Centre, Atmospheric Environment Service, three of these were located at Philpots Island, Cape Liverpool and Prince Leopold Island for that summer. In 1980, self-recording automatic weather stations were operated at Cape Sherard, Philpots Island and Cape Liverpool. Details of the observing program are given in Table 3.1 and the station locations are shown in Figure 3.1.

During 1978 and 1979, the vessels Theron and Gulf Star, and in 1980, the Polarhav, collected Synoptic marine observations which was submitted to the Atmospheric Environment Service.

3.1.4 Other Observations

Many other scientific and industrial programs have operated in the region for short periods. The observation sites from relevant programs are shown in Figure 3.1.

Winds at Wollaston and Borden islands were recorded and analyzed by the Arctic Research Establishment, Pond Inlet, and data was provided by the Environmental Protection Service, Edmonton.

3.2 SYNTHETIC DATA

The lack of marine observations has prompted some investigators to utilize archives of synoptic surface pressure charts to derive winds at fixed points offshore. These derivations are often at locations where there are no observational data; therefore, such winds are referred to as synthetic data.

Lachapelle (1980) derived geostrophic winds at three reference points (A,B,C in Figure 2.1) from sea level atmospheric pressures for the period 1946-1978. The pressures were provided by the Fleet Numerical Oceanography Center in Monterey, California on approximately a 381-km grid at six-hourly intervals.

Maxwell et al. (1980) examined a set of synoptic surface pressure charts prepared by the Arctic Weather Centre, Atmospheric Environment Service for July to November, 1974-1978. They derived surface winds for selected storms at the offshore points shown in Figure 2.1 (Thomson and Vickers reference points). These were then used to estimate sea state, structural icing and wind-chill conditions. Thomson and Vickers (1980) later extended the study to cover the 11-year period 1969-1979.

3.3 EVALUATION OF DATA SOURCES

3.3.1 Marine Observations

Weather observations from ships are not taken randomly in space or time, thus the summaries derived from them are biased. In the Arctic, ships may spend a significant part of the time tied up in port, and observations taken then are not true offshore observations. Also, ships sail along preferred routes and avoid bad weather or ice. In addition, marine observations are almost non-existent for months other than August and September. All of the foregoing deficiencies make it impossible to conduct acceptable duration or extreme value analyses on marine observations.

3.3.2 Land Stations

The land stations bordering the study area are on or near coastlines. Some are adjacent to high terrain, so that winds are locally affected. Some are located in the convergence zone resulting from the variation in roughness between water and land. Others are much higher than sea level.

The majority have short duration or intermittent periods of observation. Of all the stations, Resolute has the best record for the longest term. For that reason, Maxwell *et al.* used Resolute for their analyses of duration and extreme events.

3.3.3 Synthetic Data

The derivation of winds from mean sea level pressure is a two-step process. The first step involves computing the geostrophic wind from the sea level pressure pattern; the second step involves computing the real wind from the geostrophic wind.

One of the major inaccuracies in the first step is caused by the lack of atmospheric pressure data. This is particularly evident in the Baffin Bay area, where few weather observations exist from offshore.

To compute the real wind from the geostrophic wind, provision is made for airmass stability, local topographic effects, surface roughness, horizontal temperature gradients and pressure change. Often, average conditions are applied to adjust for these effects and large errors may exist in the application to individual cases.

3.4 ANALYSES

Results of climatological studies of the Lancaster Sound and Baffin Bay regions are based on analytical techniques carried out by a number of scientists. In general, two types of analyses are reported here. The first relates to normal climatic conditions and the second to extreme

value, duration, and event-related conditions. Climatic elements analyzed include wind, waves, temperature, wind-chill, structural icing, clouds and precipitation, ceilings and visibilities, aircraft icing, synoptic storms and air pollution potential.

3.4.1 Analyses of Normal Climate

The most recent and comprehensive study of the normal climate of the Canadian arctic islands was published by Maxwell (1980). In addition, Maxwell (1980) and Maxwell et al. (1980) studied the climate of Lancaster Sound and northwestern Baffin Bay in considerable detail.

3.4.1.1 Method of Maxwell

Maxwell et al. (1980) analyzed the general climatology of northwestern Baffin Bay for July through October.

The study area was the offshore region roughly bounded by parallels of latitude 71° and 76°N and meridians of longitude 70° and 81°W . It is the area east of Lancaster Sound depicted in Figure 1.1.

The data sources included synoptic marine observations from the period 1947-1978, which were prepared in "Summary of Surface Marine Observation" formats for the four areas 7, 11, 12, and 18 shown in Figure 2.1. Also used were data from land stations in and adjacent to the area.

Most of the foregoing data plus that from marine area 10 were used by Maxwell et al. (1980) to analyze the climate of Lancaster Sound.

3.4.1.2 Method of Duck

Duck (1979) analyzed extreme meteorological and related events in the northwestern Baffin Bay region. He included the occurrence of extreme wind, wave, and sea spray icing events when his report was updated and included in the second chapter of Maxwell et al. (1980).

The bulk of Duck's data were abstracted from the weather records of Resolute, although he also used ship observations from the period 1947-1978 to compute frequencies of wind speed and direction. The ship observations were from the area bounded by 73° and 75°N , and 70° and 80°W , grouped together and ascribed to the reference point in Figure 1.1.

Duck et al. (1977) carried out a similar analysis of extreme events in Lancaster Sound and the results apply at the other reference point shown in Figure 1.1.

3.4.1.3 Method of Thomson and Vickers

Thomson and Vickers (1980) analyzed storms in addition to observational data to evaluate extreme weather conditions in northwestern Baffin Bay. They evaluated winds, waves, sea ice, superstructure and aircraft icing, ceilings, visibility, and wind-chill during the period July 1 to November 30. Their study area was roughly bounded by 70°W and 81°W, and 71°N and 76°N.

The data source was weather charts prepared by the Arctic Weather Centre, Atmospheric Environment Service. Ship data collected by Petro-Canada in 1978 were used to re-analyze some charts. Geostrophic winds were computed at each of the four points shown in Figure 2.1 during the period of study and converted to surface winds. Those cases where the wind was 65 km/h or stronger for a period of at least six hours were considered to be storms and were selected for further analyses.

3.4.1.4 Method of Lachapelle

The wind and wave data used by Lachapelle (1980) were derived from a set of gridded 6-hourly hemispherical pressure maps compiled by the Fleet Numerical Oceanography Center in Monterey, California. The period of record began in January 1946 and ended in December 1978. There was a total of 117 maps missing of a possible 48,211, most of which (104) are missing during the period 1976-1978. The study concentrated on the period from June to October.

Three locations in Lancaster Sound were chosen for calculating winds and waves. They are 77°W, 83°W, and 89°W, all three along the latitude 74.25°N, and are referred to as positions A, B, and C respectively (see Figure 2.1). As well, winds were computed for Resolute, at 74.7°N, 95.0°W.

The "Summary of Synoptic Meteorological Observations" (SSMO) tables compiled for the Lancaster Sound-northwestern Baffin Bay region were used to verify the computed winds and waves for the marine areas. The Atmospheric Environment Service data archives were used to compare winds computed for Resolute. Individual cases were assessed using information compiled by Thomson and Vickers (1980), and personal communication on the 25 most significant storms in northwestern Baffin Bay over the period 1969-1979.

Winds at a specific location were computed using Bessel's function in cubic form. A sixteen-point grid array was used to obtain east-west (u) and north-south (v) gradients at a specific location.

Wind speed and direction were obtained from the u and v components. Hourly values were obtained by linear interpolation of the u and v components. No interpolation was done if four or more 6-hourly consecutive maps were missing. This last condition only occurred three times in 33 years, none of which were in the June to October period.

This synthetic wind derived by Lachapelle is truly geostrophic in nature, except that the wind direction is backed by 20° to approximate normal surface wind direction over water. The synthetic wind speed is assumed to be a good first approximation to the surface wind speed over water.

3.4.1.5 Other Studies

Other studies using shorter periods of record were prepared by Hill *et al.* (1978) for Cape Charles Yorke, Griffith Island, Cape Anne, Rodd Bay and Somerville (see Figure 3.1); by Headley (1979a, 1979b) for Craig Harbour and Dundas Harbour; by Jakobsson (1979) for Hamilton Island; by Woodrow (1972) for Pond Inlet; and by Alt (1978), Bliss (1972), Keeler (1964) and others from meteorological conditions on and in the vicinity of Devon Ice Cap.

Thompson (1980) analyzed wind direction from marine observations, including those taken by Petro-Canada for Lancaster Sound.

4.0 CLIMATIC CONTROLS

The climate of northwestern Baffin Bay depends primarily on the character of the solar energy input, weather systems, topography, and the nature of nearby land and sea surfaces.

4.1 RADIATION

The study area lies at approximately the same latitude as Resolute, the nearest long-term radiation observing station. The mean monthly global solar radiation varies from zero in January during the polar night (from early November to early February) to over 500 langley/day in June. The mean annual net radiation experienced is near 10 kilolangley, resulting from mean monthly deficits of 20-45 langley/day during the October-to-April period, but excesses of about 200 langley/day in June and July. Mean daily radiation observed at Resolute is shown in Figure 4.1.

4.2 ATMOSPHERIC CIRCULATION

Cyclonic activity is frequent in Baffin Bay throughout the year, but is most intense in winter. The preferred trajectory for lows affecting the area is northwards through Davis Strait; most cyclonic systems are in the occluded phase by the time they affect northwestern Baffin Bay. Occasional systems tracking from Keewatin over Baffin Island or from the west along Parry Channel also occur.

These large-scale pressure systems control the wind, cloud and precipitation regimes in the region. They import cold or warm air, depending on the orientation of the storm tracks.

4.3 TOPOGRAPHIC EFFECTS

The topography of the islands bordering the study area is important. Devon, Bylot, and Baffin islands are all mountainous along their eastern coasts, and onshore flows forced aloft along those coasts greatly enhance precipitation totals. Principally, however, the mountains tend to contain weather systems that have come north through the Davis Strait. The tendency for such systems to be occluded is mainly a result of the Greenland ice cap to the east, which restricts the supply of warm air to the low pressure centres. Such a supply is necessary to deepen or at least maintain the

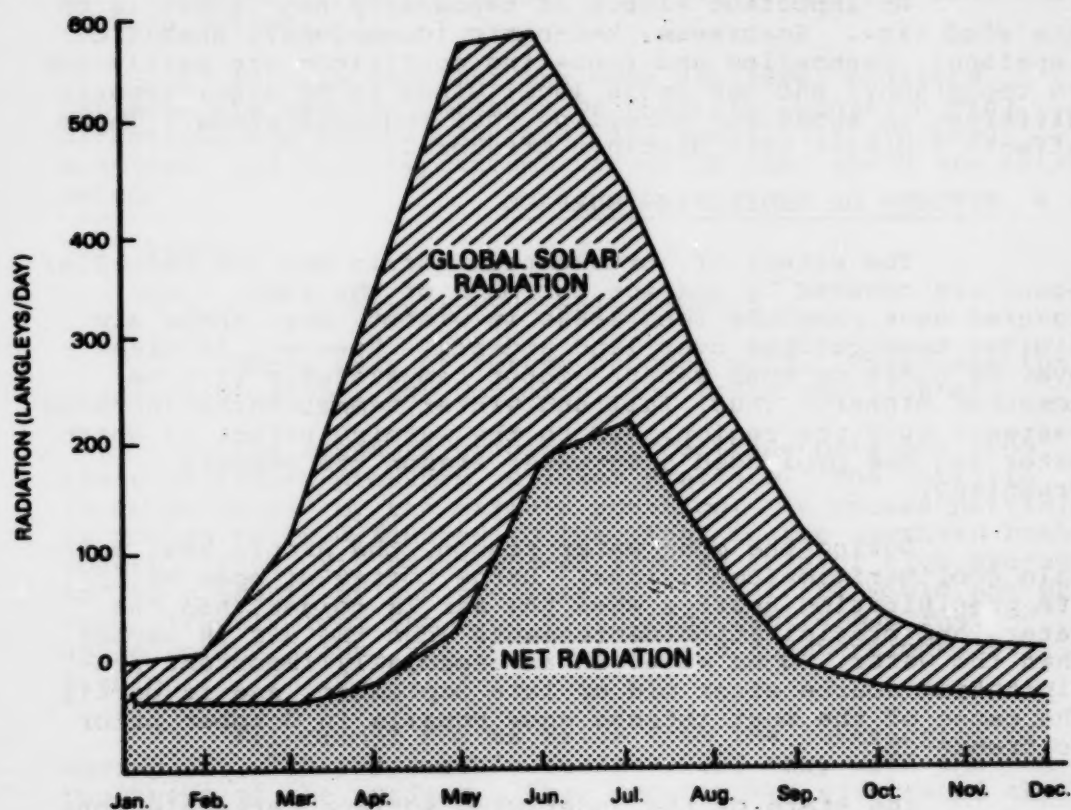


Figure 4.1 Mean daily radiation values observed at Resolute A (1970-1976).

intensity of lows. The mountains are also a physical barrier to storms approaching the study area from the west or southwest.

An important effect of topography near shore is on the wind flow. Seabreeze, katabatic (downslope), anabatic (upslope), channeling and funneling conditions are partly due to topography, and can cause local winds to be significantly different in speed and direction than regional winds. These effects diminish with distance offshore.

4.4 EFFECTS OF UNDERLYING SURFACE

The waters of northwestern Baffin Bay and Lancaster Sound are covered by sea ice for much of the year. Ice-covered seas resemble land areas in winter, when there are similar temperatures over land and sea. However, in areas over or close to open water, winter temperatures will be somewhat higher. Thus, fall and winter temperatures increase eastward over the region, due to the warming effect of North Water and the prolonged open water season off western Greenland.

During the open water season, the Arctic seas maintain cool maritime conditions. Large bodies of open water are precipitation sources when the air is colder than the water, and precipitation depressants when the air is warmer than the water. Open water is an especially important precipitation source after mid or late September, and is partly the cause of the most intense snow squalls in October prior to freeze-up.

The state of the underlying surface certainly controls the climate and determines the length of the drilling season.

5.0 PRESSURE AND WIND

Wind is perhaps the most important climatic element, because it causes adverse environmental conditions, such as waves, freezing spray, wind-chill, and ice floe and iceberg motion.

In this section, the mean sea level pressure patterns are examined because of their influence on wind directions and speed. Average wind conditions are then examined, and finally extreme values of wind speed are estimated.

5.1 PRESSURE

5.1.1 Pressure-Wind Relationship

Three sets of forces produce wind. These are the pressure gradient, the Coriolis, and frictional forces.

The pressure gradient force transports air from areas of higher pressure to lower pressure. The Coriolis force is caused by the earth's rotation. It causes particles in motion to be deflected to the right in the northern hemisphere. Thus, air being forced from an area of high pressure to low pressure by the pressure gradient force would not proceed directly from the high to the low centre but instead would rotate around the low centre in a counterclockwise fashion.

Frictional forces arise from the interaction of moving air with the earth's surface, and vary with the roughness of the surface. They counter the effects of the pressure gradient and Coriolis forces, so that the resultant flow is inward towards the low-pressure centre and outwards from a high.

Generally, winds blow counterclockwise around a low centre with a slight inward component that varies with the magnitude of the frictional forces. Similarly, the flow around a high is clockwise with a slight outward component.

5.1.2 Mean Pressures

Maps showing mean monthly pressures for January, April, July, August, September, and October are shown in Figures 5 to 10.

A low pressure area exists over Baffin Bay in all seasons. However, it is more intense in winter than in summer, producing a stronger pressure gradient in the winter months. The speed of the wind varies directly with the strength of the pressure gradient.

5.2 WIND DIRECTION

Wind roses for the land stations, Maxwell's marine areas and Lachapelle's point A are superimposed on the mean sea level pressures in Figures 5.1 to 5.6.

In January, and April, the prevailing wind directions are consistent with the pressure at most locations, including point A where the winds were derived by Lachapelle. This is due to the relatively large pressure gradient force that dominates during these months. One exception is Pond Inlet, where it is believed that local topography influences the wind direction.

During July and August, the prevailing winds are not as consistent with the pressure patterns, due to the lower pressure gradient. Areas of pronounced inconsistency are Dundas Harbour and Maxwell's area 11. The inconsistency at Dundas Harbour is probably due to topographic influences. The wind rose for marine area 11 is highly skewed in the east and west directions, suggesting that air flow is being channelled through Lancaster Sound.

During September and October, the pressure gradient begins to increase, causing the prevailing winds to again become better aligned with the pressure pattern at all locations, including Lachapelle's point A and Maxwell's marine areas.

The longest records near the study area are the observed winds at Resolute Bay and the derived winds at Lachapelle's point A. In both cases, the prevailing wind directions are in close agreement with the pressure patterns for all months except July and August.

In July and August, the regional pressure gradient is very light, so that local effects appear to control the direction of the wind, especially at coastal land stations. This is evident in the Resolute and Dundas Harbour wind roses and pressure patterns shown in Figures 5.3 and 5.4.

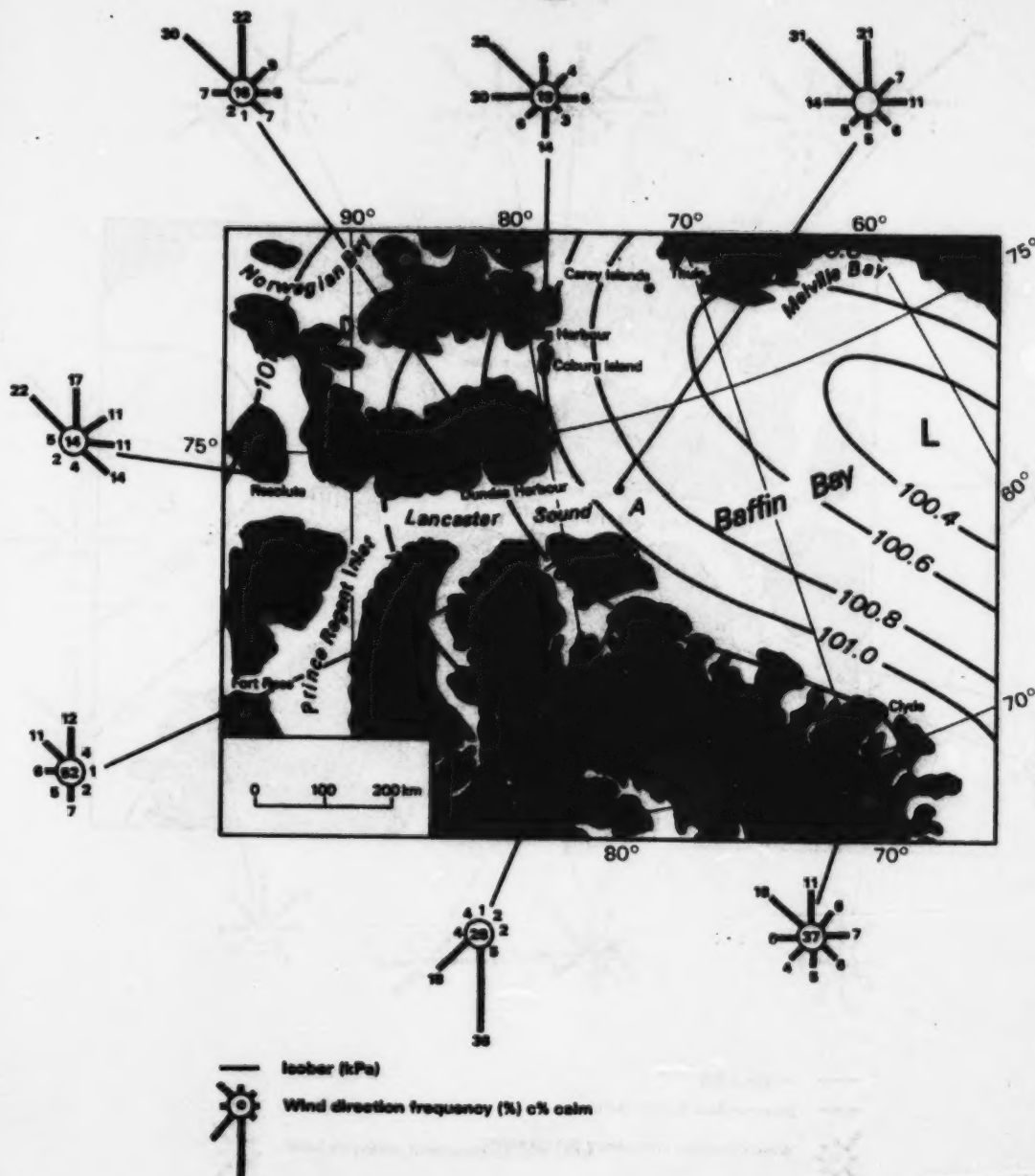


Figure 5.1 Mean sea level pressure and wind roses for January.

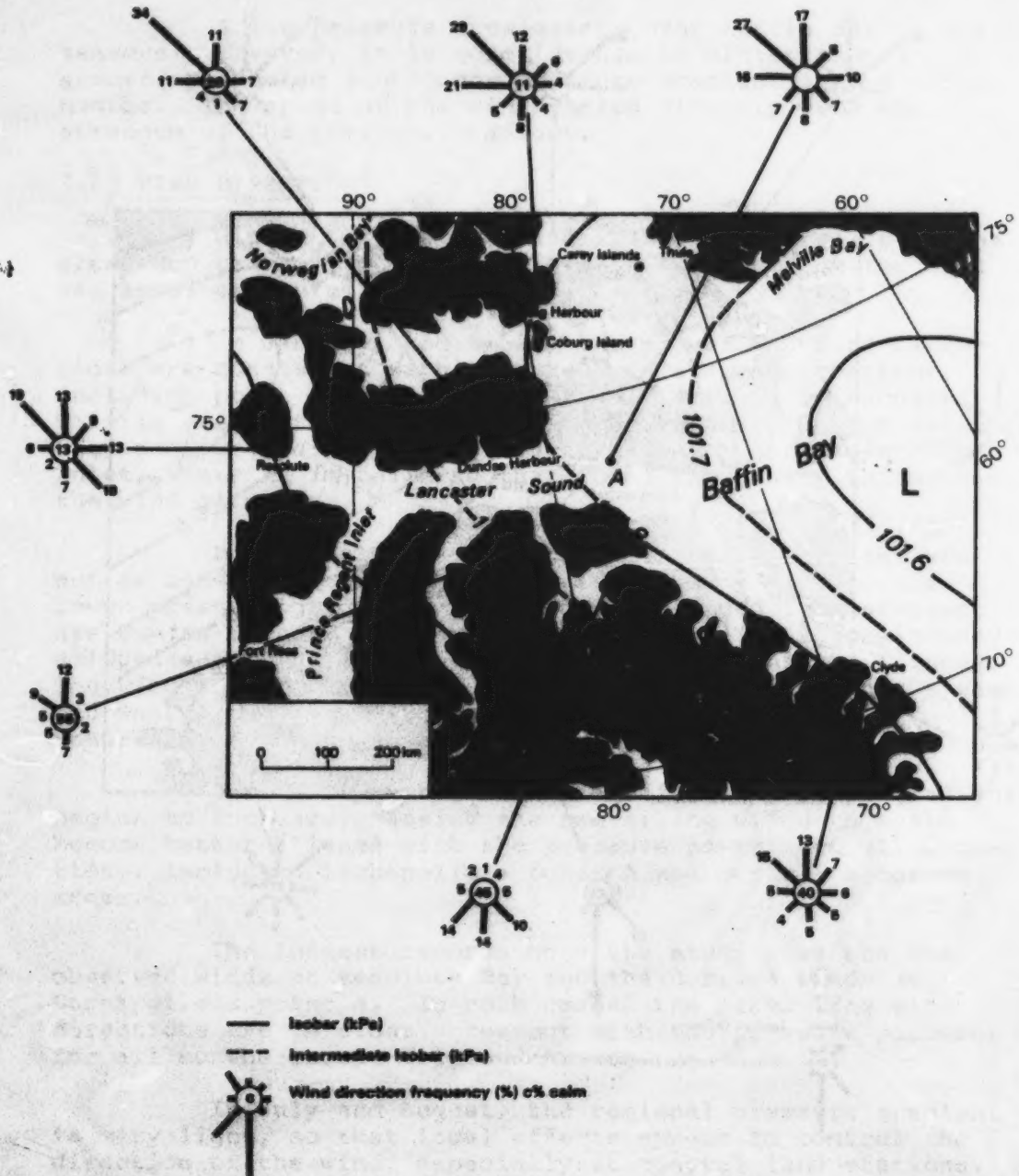


Figure 5.2 Mean sea level pressure and wind roses for April.

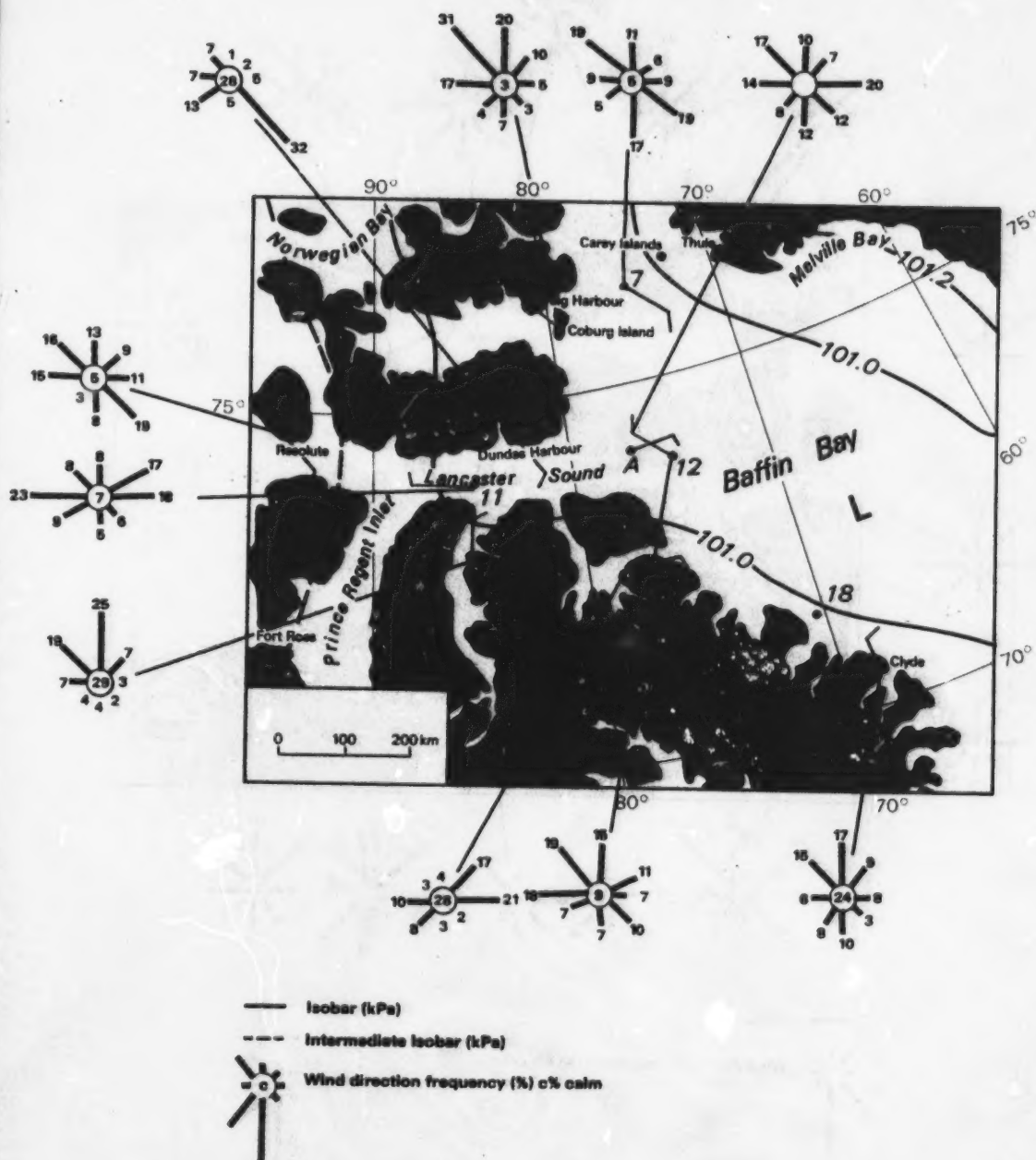


Figure 5.3 Mean sea level pressure, wind roses and prevailing winds for July.

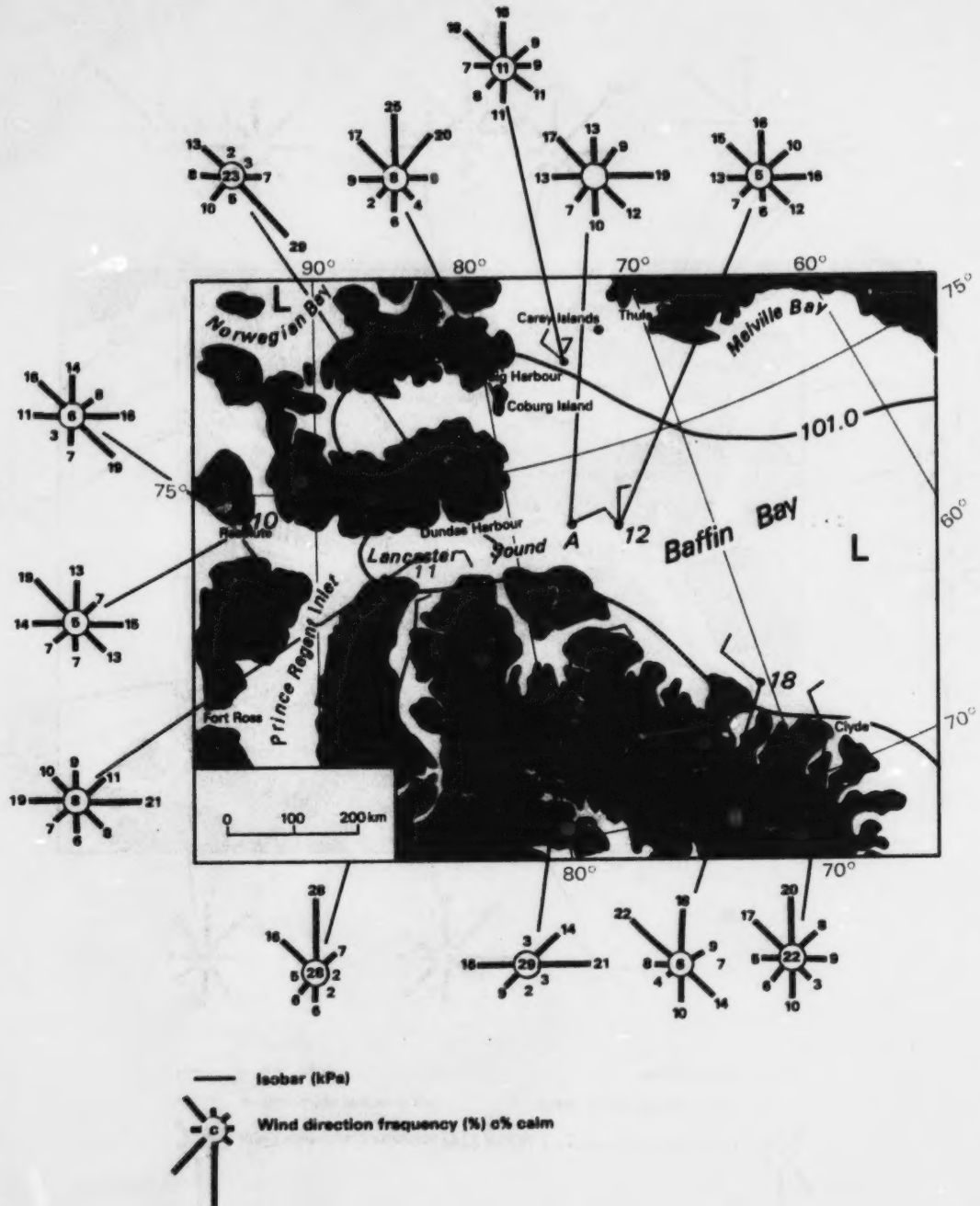


Figure 5.4 Mean sea level pressure, wind roses and prevailing winds for August.

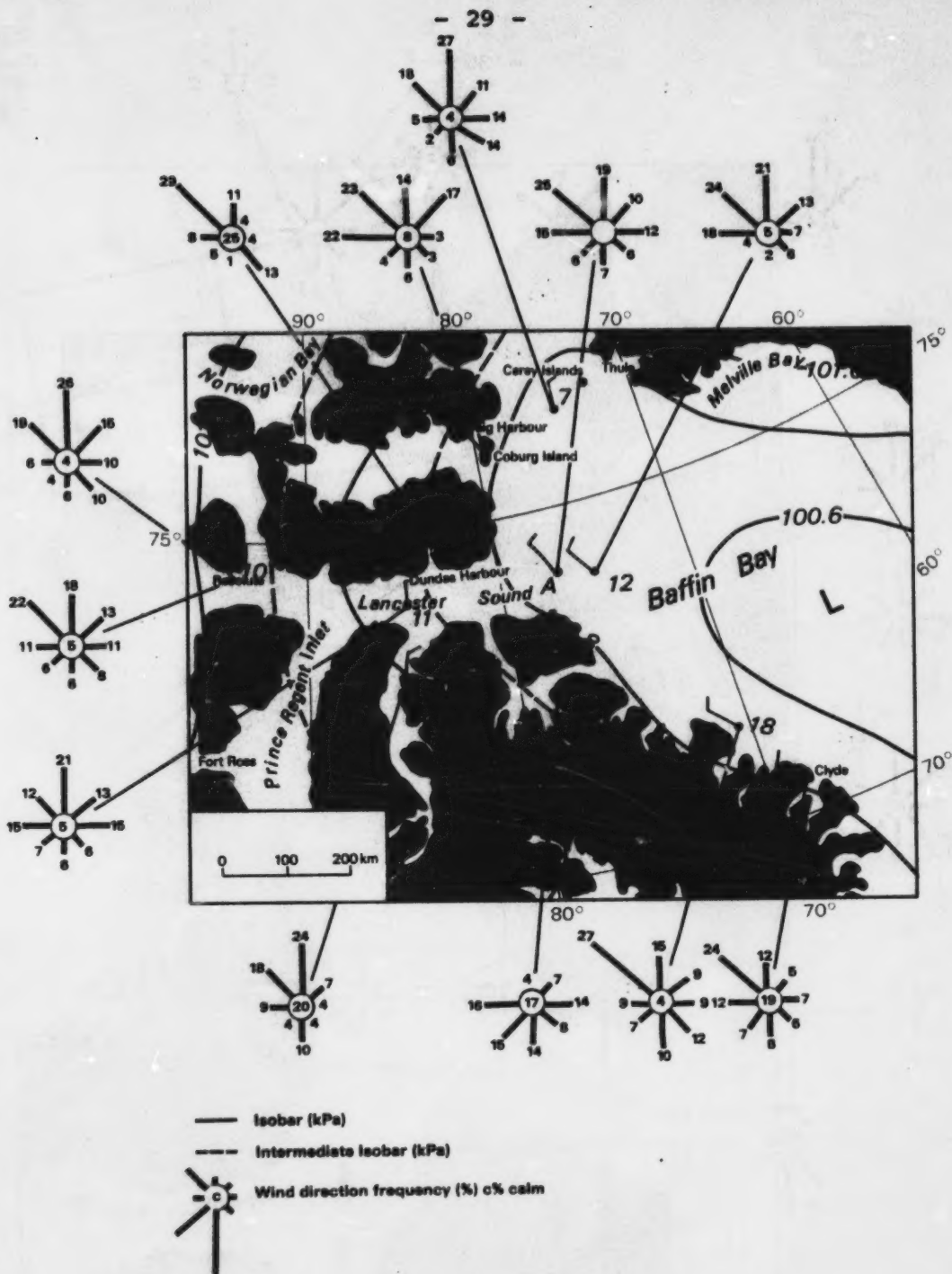


Figure 5.5 Mean sea level pressure, wind roses and prevailing winds for September.

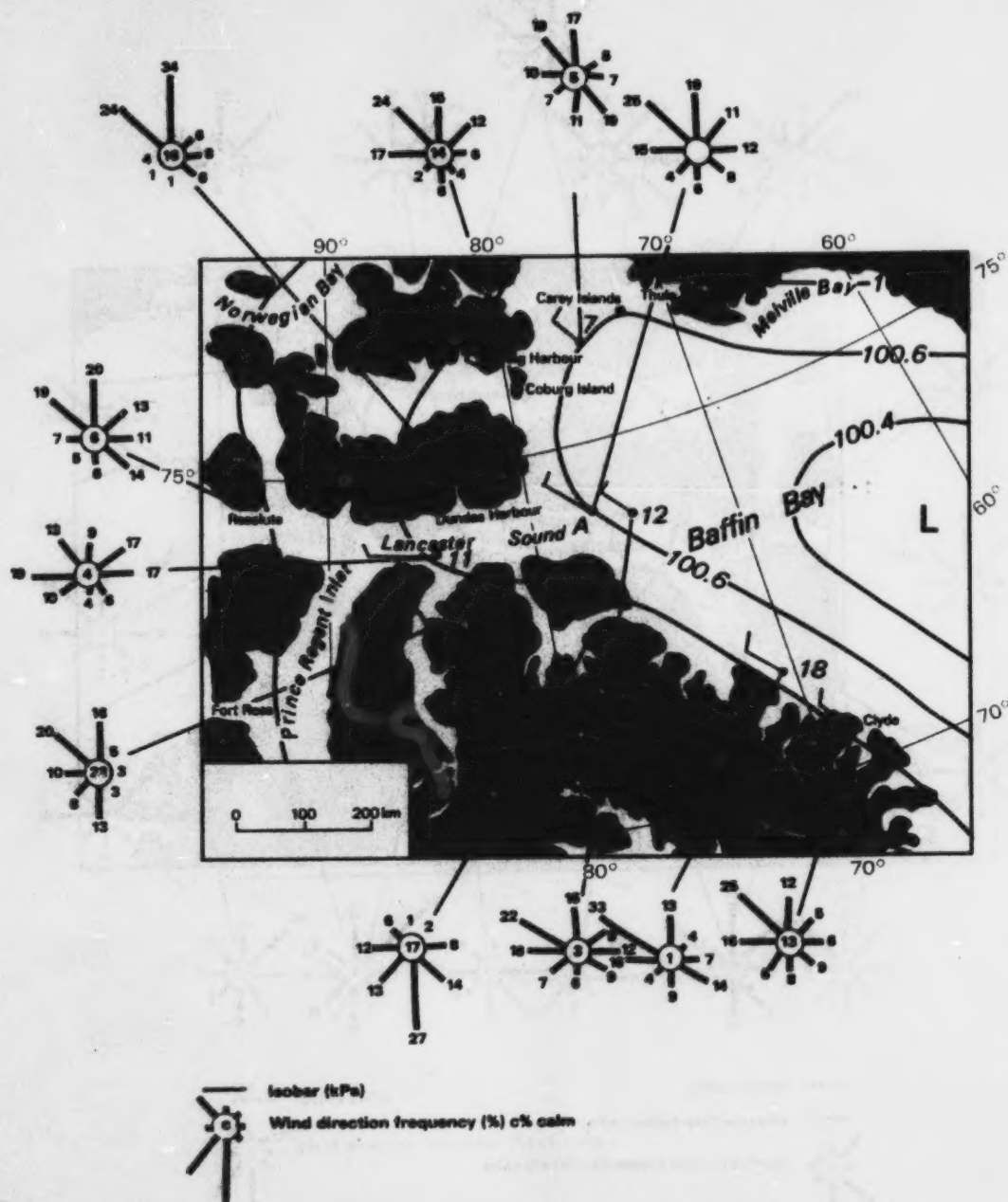


Figure 5.6 Mean sea level pressure, wind roses and prevailing winds for October.

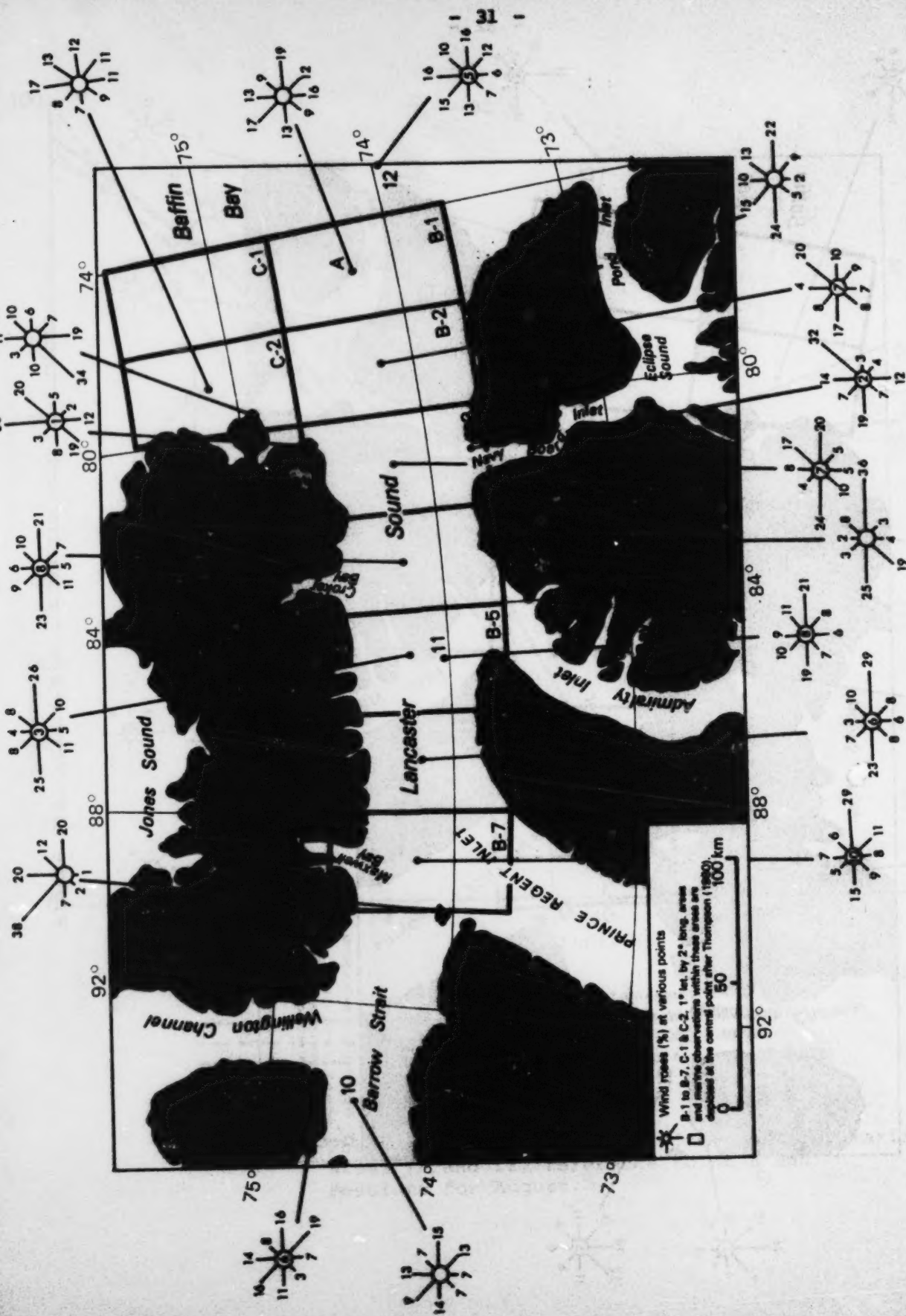


Figure 5.7 Wind roses for marine and land locations for August.

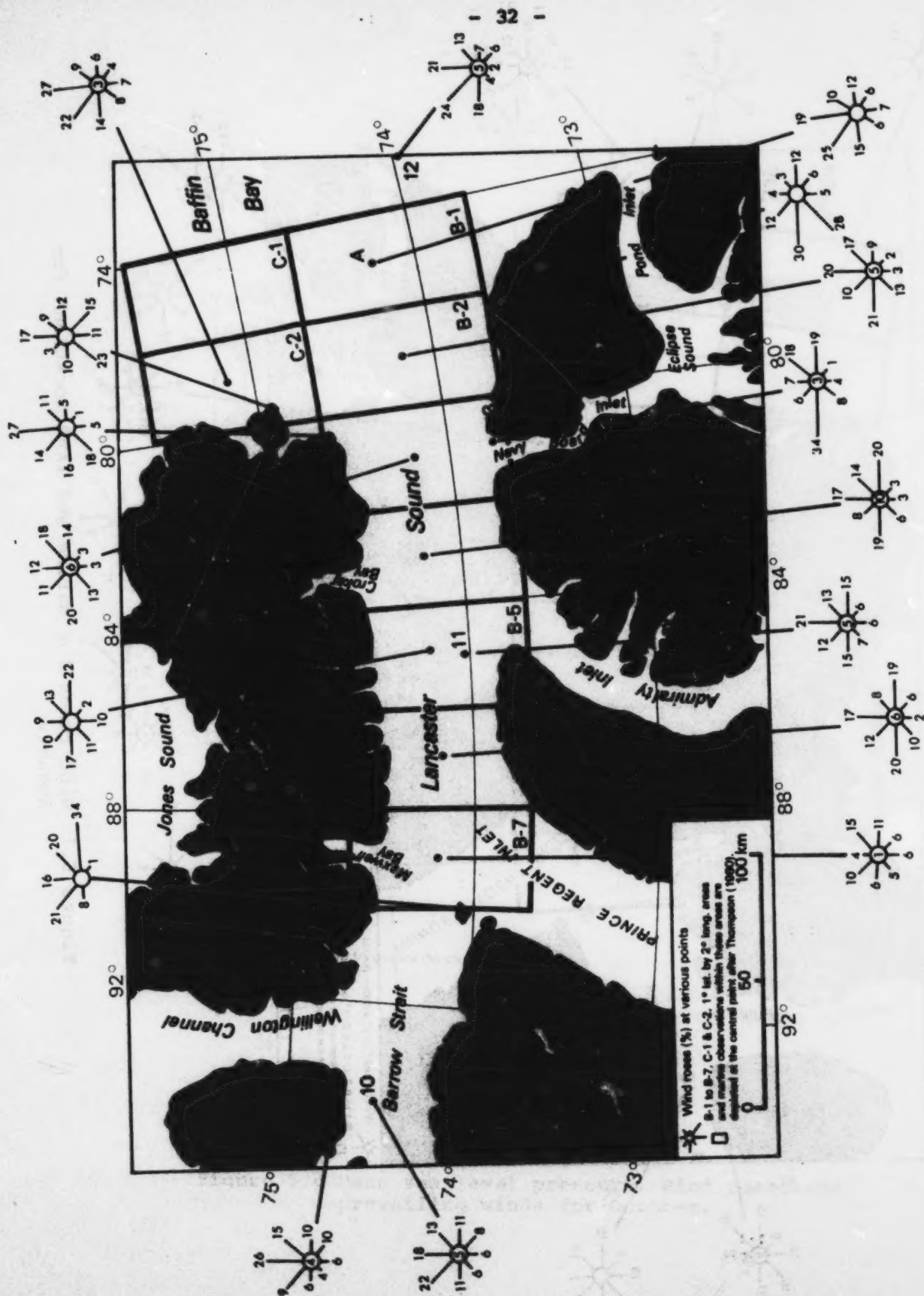
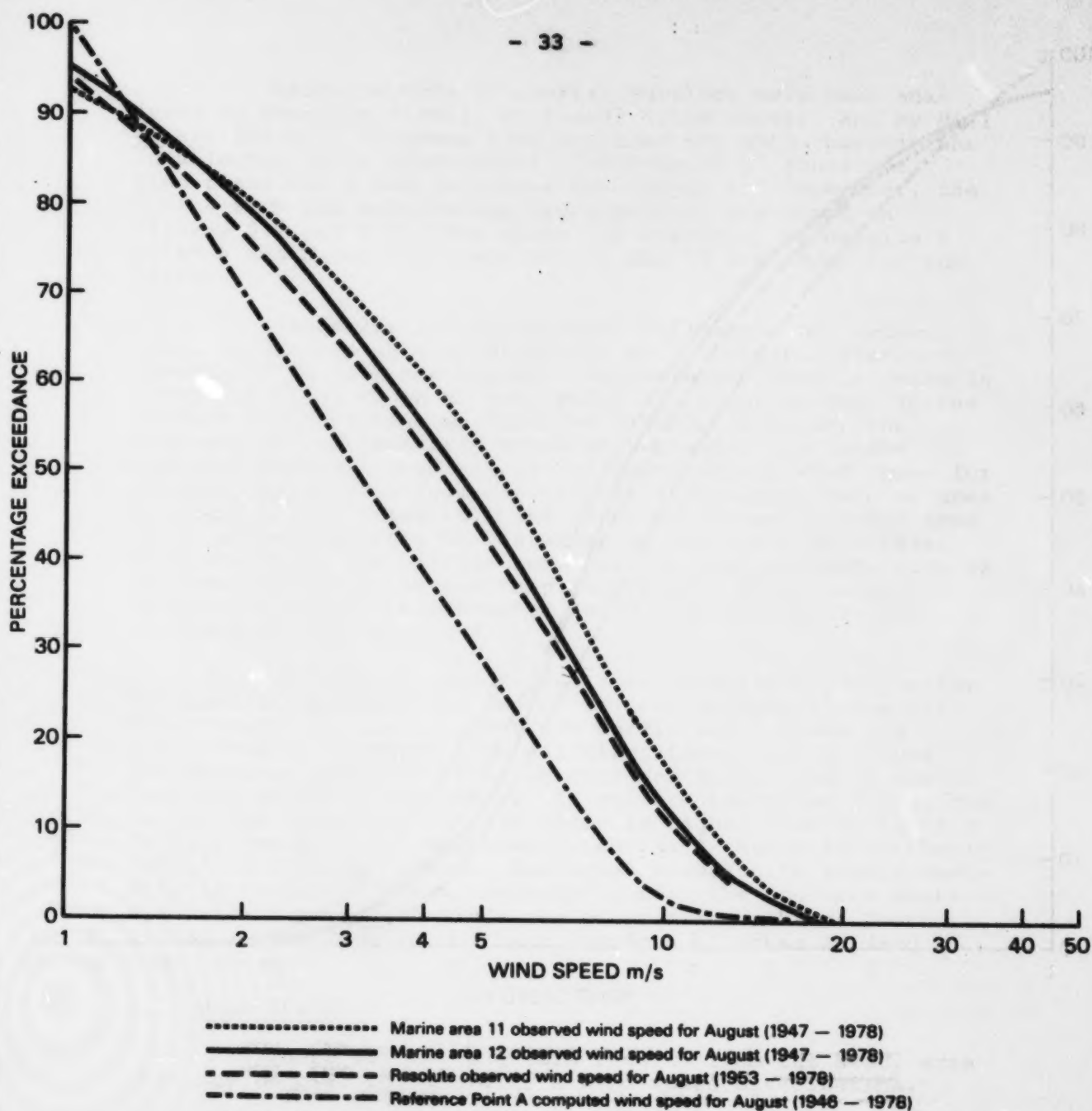


Figure 5.8 Wind roses for marine and land locations for September.



1 m/s = 1.94 kt

1 kt = 1.85 km/hr

Figure 5.9 Percentage exceedance for wind speed for marine areas 11 and 12, reference point A and Resolute for August.

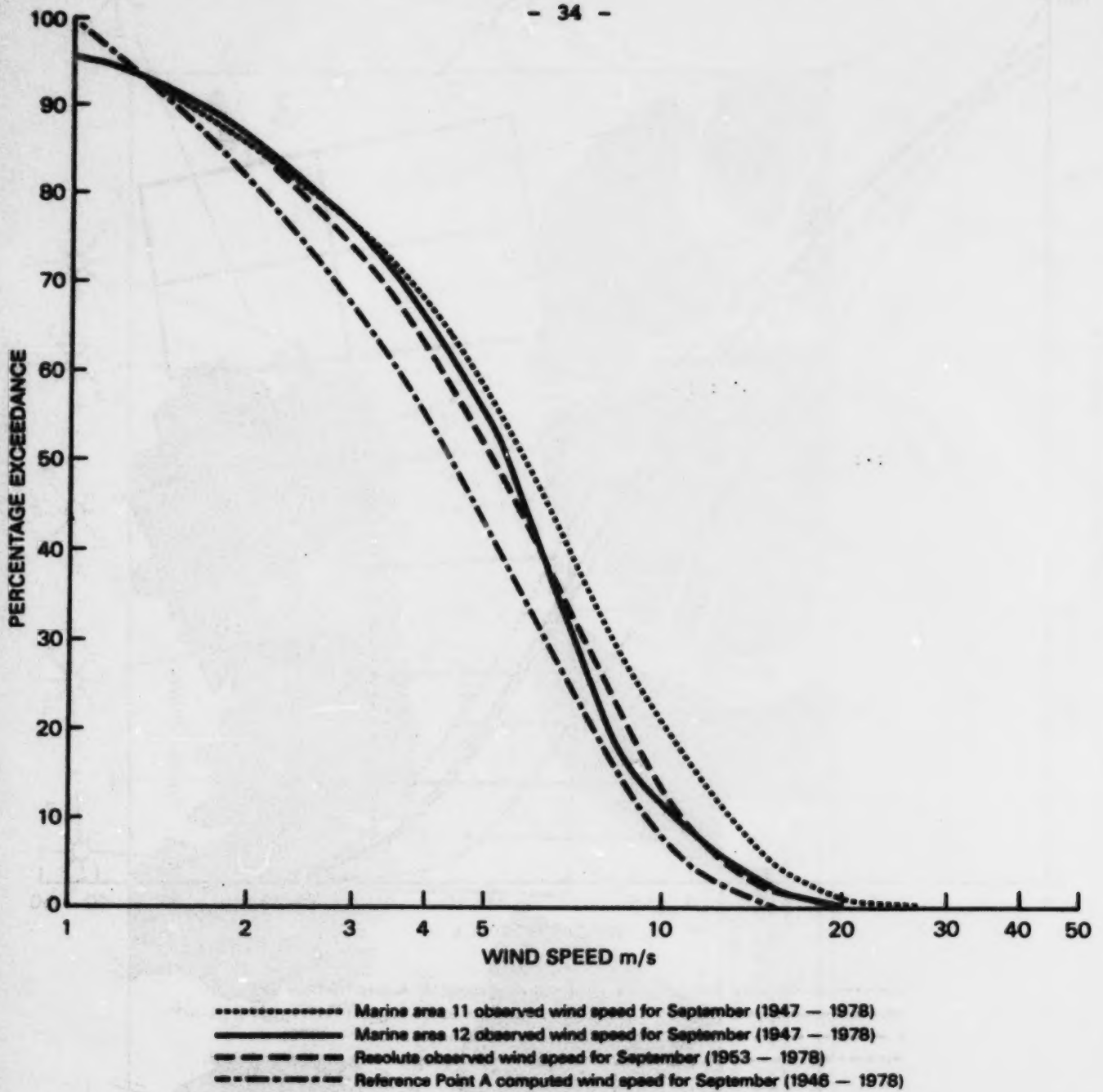


Figure 5.10 Percentage exceedance for wind speed for marine areas 11 and 12, reference point A and Resolute for September.

Other records of shorter duration have been analyzed by Thompson (1980), by Fraser (this study), and by Hill et al. (1978). Thompson also examined the ship observations in selected cells measuring 1° latitude by 2° longitude. Wind roses for these locations for August and September, the months with the most marine observations, are shown in Figures 5.7 and 5.8. The roses for Resolute, Lachapelle's point A and Maxwell's areas 10, 11 and 12 are shown for comparison.

Seabreeze and topographic influences may cause local variations in wind direction at all coastal stations, especially in July and August. In September, the increase in northerly winds shown at grid point 11 is not evident in the refined distributions by Thompson (1980). However, the increase in northwesterly winds in September due to the regional pressure gradient is reflected in the wind roses for offshore areas free from topographic influences, such as area C-2, and points A and 12. The winds in Lancaster Sound tend to be either easterly or westerly, as are those at coastal stations where the terrain contours run east to west, such as at Cape Charles Yorke and Cape Liverpool. These suggest a channeling effect in Lancaster Sound that extends as far eastward as grid area B-3.

In summary, wind directions at point A are similar to those at Resolute and appear to best represent true offshore conditions in northwestern Baffin Bay. Winds are significantly frequent from all directions, with a slight dominance of easterly winds in July and August and of northwesterly winds in September. In eastern Lancaster Sound, the percentage frequency of east winds is higher than at point A in July and August. Northwest winds at A change to northerly off eastern Devon Island. Northwest winds shift toward westerly in Lancaster Sound, especially near the southern shore. Significant northeast winds can occur off southeast Devon Island, especially in northern sections of areas B-2 and B-3.

5.3 WIND SPEED

There are no long-term records from the study area that may be used to determine a wind speed distribution.

The best available data are the records from Resolute, the observations from Maxwell's marine areas 11 and 12, and the derived winds at Lachapelle's points A and B.

Wind speed distribution for each of these locations except point B, are shown in Figures 5.9 and 5.10 for August and September respectively. Wind speeds in September are stronger at all locations than in August. This is consistent with the significant increase in pressure gradient shown for September in Figure 5.4 compared to that for August in Figure 5.3.

Lachapelle's derived wind speeds for point B were examined and the curve for September is almost identical to that shown for Resolute in Figure 5.10. His method showed similar distributions from month to month at points A and B, but wind speeds at B are consistently higher than at A during July to September. The same is true of observed winds at points 11 and 12. Lachapelle's winds at B give a good first approximation to the true surface wind, except they do not reflect topographic effects. For that reason, the results are not shown here.

In both August and September, the strongest winds were observed in area 11, followed by area 12 and Resolute. The weakest winds are at point A, especially in August (Figure 5.9), when the regional pressure gradient appears to have less influence on the wind flow than local conditions. The curve at A for September is closer to the others shown in Figure 5.9, because the regional pressure gradient dominates the wind flow in this month.

On the basis of pressure patterns for August shown in Figure 5.3, one can not make any definitive statement about comparable wind speeds. However, in September, wind speeds at the four locations shown in Figure 5.10 should be similar, based on an examination of the pressure gradient depicted in Figure 5.5. Note the good fit between Resolute and area 12, which is the basis Maxwell *et al.* used to demonstrate the compatibility of the Resolute wind data to conditions in the study area. One would expect more similarity between the distributions for points A and 12; however, the fit is better in September than in August.

Lachapelle found that, for other areas, his technique produced results in close agreement with other sources of long-term data. In the Baffin Bay - Lancaster Sound region, Lachapelle's technique would understandably not provide such close agreement during July and August, when the regional pressure gradient is a poor indicator of the true

surface wind speed. The distribution at A for September may be a good approximation of actual conditions over the long-term. That for area 12 may be too high, because the small sample of observations may not be representative of long-term conditions.

The wind speeds shown for Resolute in Figures 5.9 and 5.10 were not adjusted upward to better represent offshore conditions. Such an adjustment would displace the Resolute curves close to those shown for area 11. For design purposes, it is felt that the distributions shown for area 11 are representative of offshore wind speeds, despite the small sample size. Area 11 has the most observations of any marine area in the region and the majority were taken in August and September. No distributions for marine areas are shown for July, because it is believed that the marine data sample is too small in this month to give reliable results.

Winds offshore are calm only 3 to 5% of the time, much less than at coastal land stations. Wind speeds normally increase each month during the open-water season, with the most notable change in September. Cyclonic activity increases in frequency and intensity as the season progresses, and is the main cause of the wind regime. In marine area 11 in September, wind speeds exceed 5 m/s (10 knots) 59% of the time but exceed 17 m/s (33 knots) only 3% of the time. Wind speeds, on the average, are higher in Lancaster Sound than other parts of the region. It is believed that this is due to the funneling and resulting acceleration of east and west winds. Dunbar (1979) reported that funneling of air through Smith Sound results in increased low-level wind speeds, according to pilot reports.

5.4 DURATION OF WINDS

The discontinuous nature of synoptic marine observation records makes it impossible to conduct wind duration analyses. Maxwell assumed that the Resolute wind speed regime is reasonably representative of the study area, and used it to indicate the durations to be expected. He made no adjustments to account for differences between coastal offshore regimes. Table 5.1 shows the number of duration events lasting longer than 24 h for winds greater than 17, 26, and 35 kt and the maximum duration of these events. Values are given for each month of the July-to-November period and are based on data collected during 1953 to 1972.

5.5 EXTREME WINDS

The classical approaches to conducting extreme value analyses require long-term, continuous records. Resolute is the closest station to the area that has such records, and these were used by Maxwell et al. (1980) to compute return period values of winds for northwestern Baffin Bay and Lancaster Sound. The results are shown in Figures 5.11 and 5.12.

In these computations, Maxwell et al. adjusted the Resolute wind during the open water period to provide for the lesser frictional effects over water. The data covered the 1953-1978 period.

The values shown are average one-minute values; Corresponding gust values may be estimated by multiplying by 1.28.

Extreme wind speeds are estimated to be similar in Lancaster Sound and northwestern Baffin Bay, although they are slightly higher in Baffin Bay. The extreme hourly speed, as shown in Figures 5.11 and 5.12 is estimated to be 56 kt in northwestern Baffin Bay and 57 kt in Lancaster Sound for a 20-year return period. The reference points to which these estimates apply are shown in Figure 1.1.

A rigorous study of the directional distribution of extreme wind has not been undertaken. However, Lachapelle found a dominance of east or southeast extreme winds. Thomson and Vickers (1980) conclude that in northwestern Baffin Bay, winds 35 kt or stronger and lasting 6 h or more are predominantly from the northwest or southeast. East or west winds dominate in Lancaster Sound, but variations occur near shore. For example, Headley (1979b) reported that a destructive storm at Dundas Harbour on 29 June 1927 had hurricane force winds from the northeast.

Table 5.1 Number of duration events longer than 24 h and maximum duration length (h) for three wind-speed classes based on the complete period of record of Resolute data from 1953-72. No adjustments were made to account for coastal-offshore differences.

Wind speed class	Greater than 17 kt		Greater than 26 kt		Greater than 35 kt	
Month	No. of Events	Maximum Length	No. of Events	Maximum Length	No. of Events	Maximum Length
July	47	145	7	35	0	15
August	53	162	17	75	2	39
September	53	87	8	56	4	36
October	95	83	11	37	0	12
November	66	142	18	59	4	48

Source: Maxwell et al. (1980).

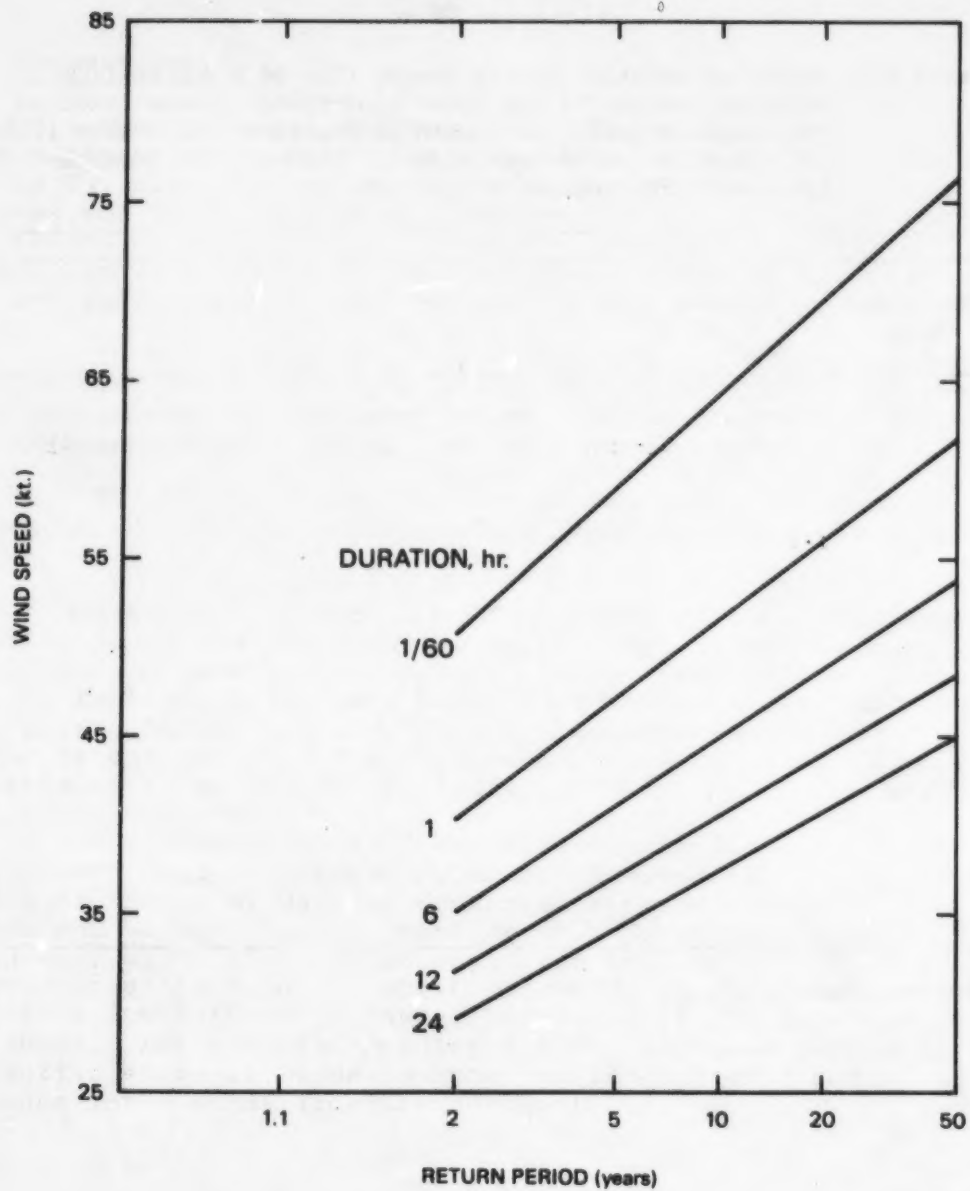


Figure 5.11 Estimated design wind speeds for the July-to-October period in northwestern Baffin Bay.

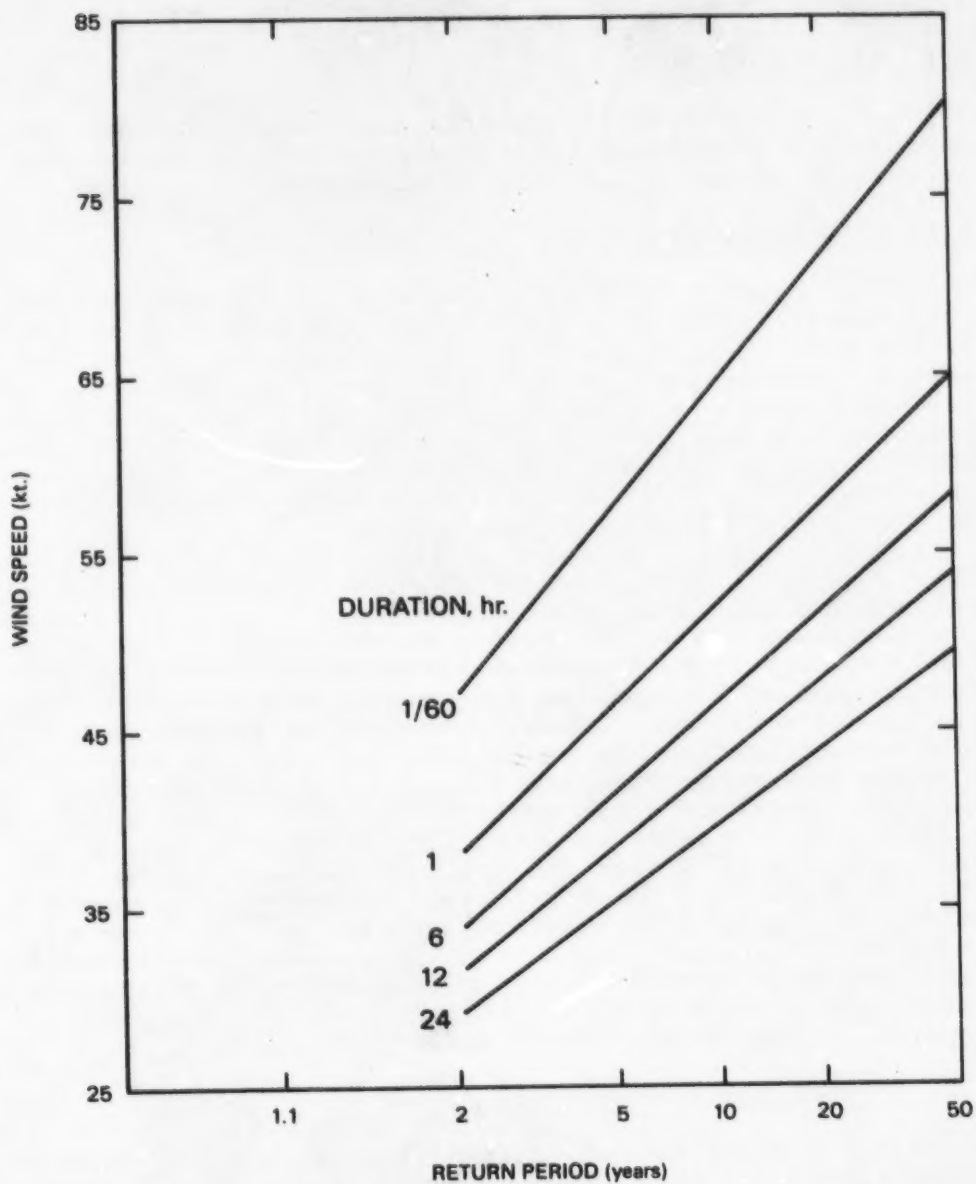


Figure 5.12 Estimated design wind speeds for the July-to-October period in Lancaster Sound.

6.0 AIR TEMPERATURE

Air temperature partly determines the open water period, the amount and rate of superstructure icing, the rate of sea ice formation and the comfort level of workers.

6.1 MEAN AIR TEMPERATURE

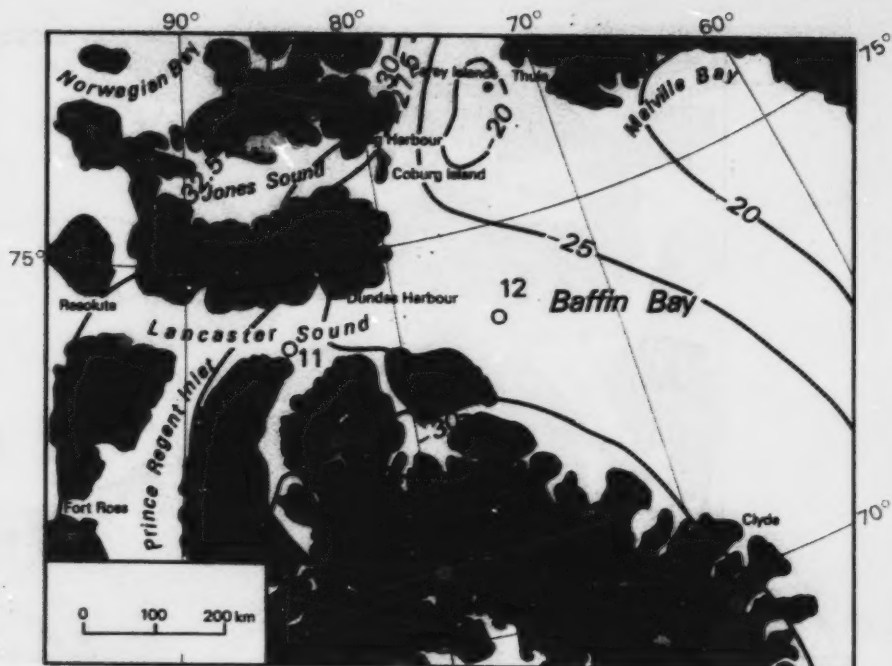
Maps of mean daily temperature for January, May, July, August, September and October are presented in Figures 6.1 to 6.6. During the fall to spring period, there is an east-to-west temperature gradient over the study area, which is most intense in mid-winter. The relatively warm West Greenland Current and the North Water raise the temperatures in northern Baffin Bay. Polynyas probably exert localized influences, but these are too variable from year to year to be shown on the scale of these maps.

During the summer, the mean temperature over water is relatively uniform and reaches 3° to 4°C. Land areas at low elevation are a few degrees warmer. Mean temperatures on land depend very much on the existence or absence of snow cover, type of surface and vegetation, distance from the coast, and elevation. Towards the end of summer, a temperature gradient is re-established and increases gradually over northwestern Baffin Bay during the fall months. The temperature gradient increases in intensity over eastern Parry Channel in October, with mean values decreasing westward from -5°C near the proposed drill sites to about -15°C at Resolute. The northerly flow brings progressively colder outbreaks of arctic air from the cold sources over the Arctic Ocean and Greenland into the region. The sub-zero isotherms move southward faster than the edge of the ice cover, which makes the fall the worst season for superstructure icing (Dunbar 1969).

6.2 EXTREME AIR TEMPERATURES

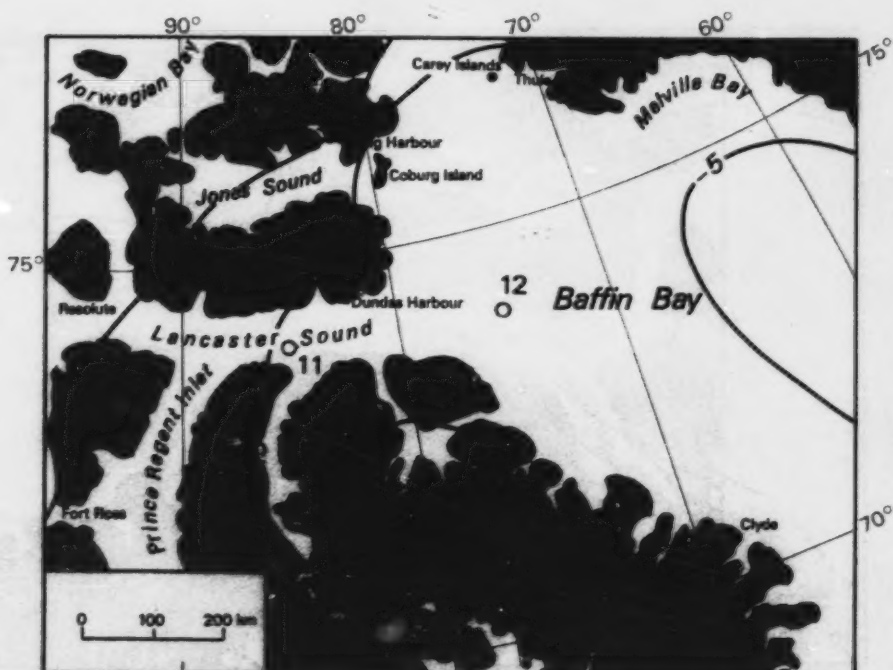
Monthly extreme maximum temperatures at land stations range from near 20°C in July or early August to near 0°C in winter. Extreme minima vary from -5°C in summer to -50°C in winter.

A summary of mean daily and extreme temperatures during the July to November period is shown in Table 6.1 for both land and marine locations. The mean values for the marine areas are similar to those at the land stations in July and August. Marine stations are warmer during September and October.



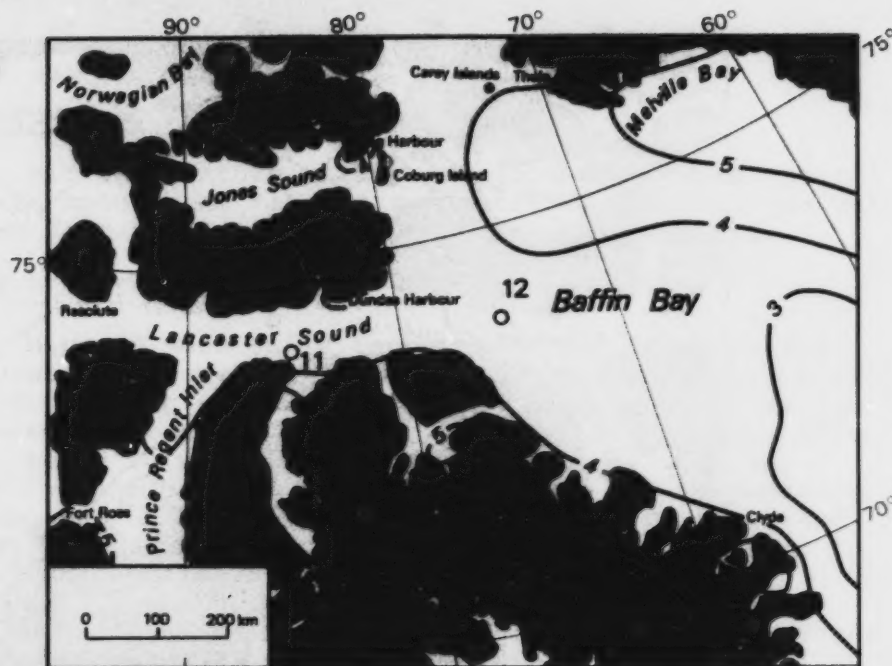
— Isotherm (°C)
11, 12 Marine area grid points

Figure 6.1 Mean daily temperatures in January.



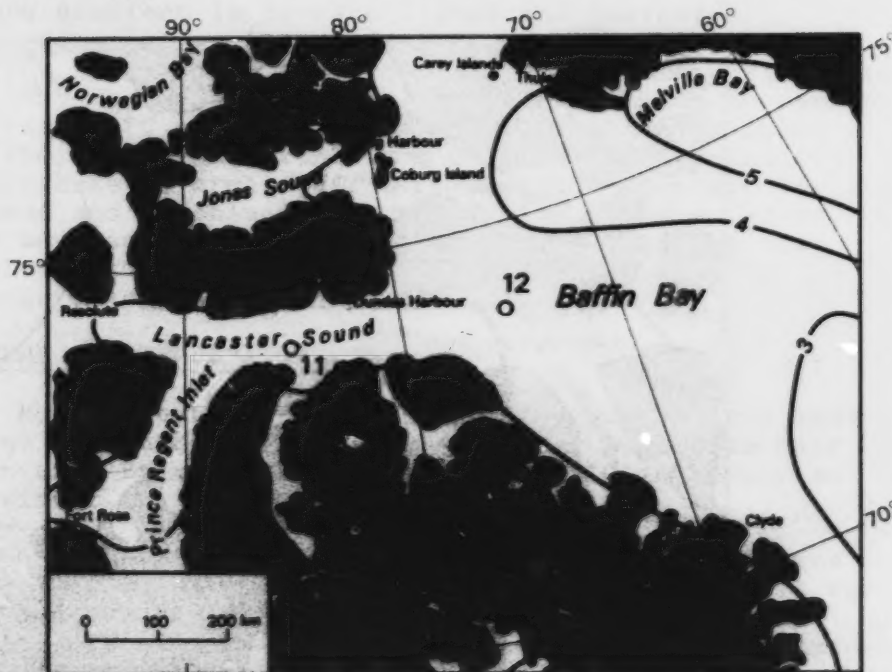
— Isotherm (°C)
11, 12 Marine area grid points

Figure 6.2 Mean daily temperatures in May.



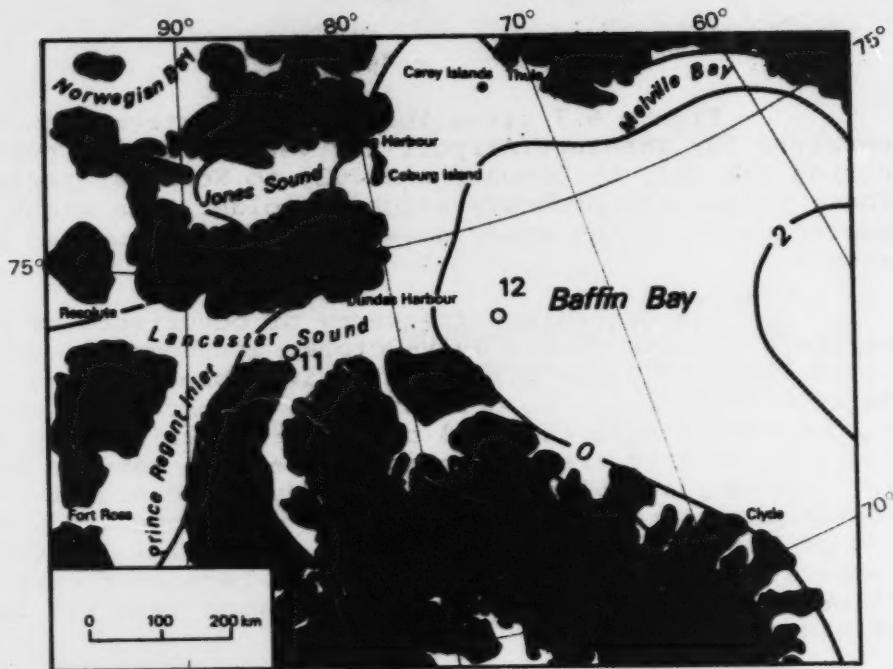
— Isotherm (°C)
11, 12 Marine area grid points

Figure 6.3 Mean daily temperatures in July.



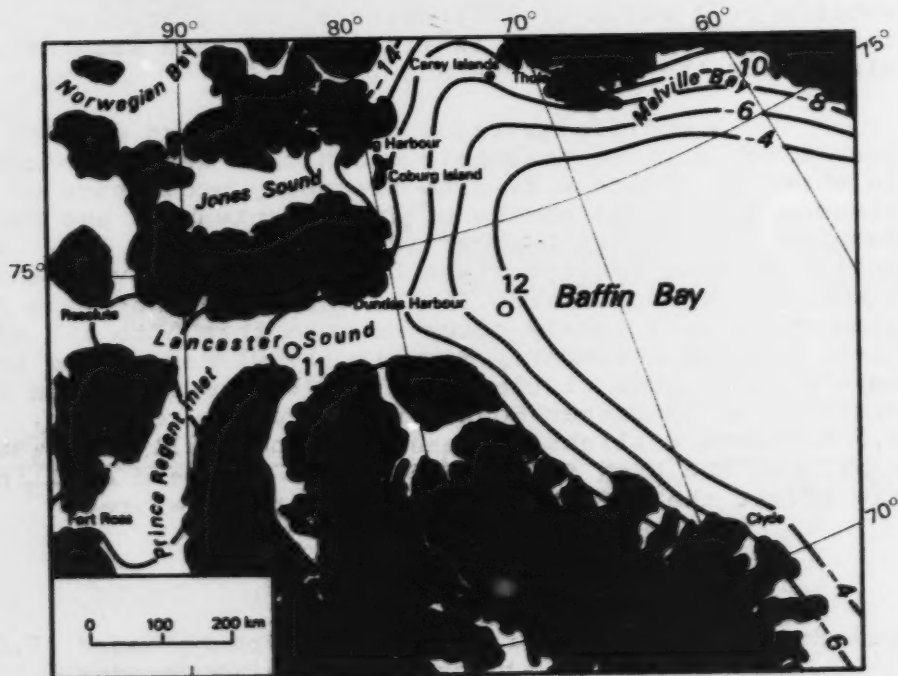
— Isotherm (°C)
11, 12 Marine area grid points

Figure 6.4 Mean daily temperatures in August.



— Isotherm (°C)
11, 12 Marine area grid points

Figure 6.5 Mean daily temperatures in September.



— Isotherm (°C)
11, 12 Marine area grid points

Figure 6.6 Mean daily temperatures in October.

Figure 6.7 gives the expected extreme minimum temperature for Resolute Airport for various return periods during the July to October and July to November periods. These values are probably slightly colder than might be expected close to the study area, which is influenced by open water.

The percentage frequency of occurrence of air temperature classes during July-October is shown for grid area 11 in Table 6.2, for grid area 12 in Table 6.3, and for Resolute in Table 6.4. In grid area 12, temperatures are between 0.1 and 4.4°C more than 65% of the time during July and August. In grid area 11, temperatures are between 0.1 and 6.7°C more than 65% of the time in July and August. In September, temperatures are between -2.1° and 2.2°C more than 60% of the time in both grid areas 11 and 12. In October, temperatures vary over a wider range, because freeze-up allows air temperature to drop more often into the lower temperature ranges.

6.3 WIND-CHILL

The wind-chill factor is a measure of the rate of heat loss from an exposed object, measured in units of watts/m². A value of 2700 watts/m² for example, indicates exposed flesh is liable to freeze within half a minute for the average person (AES 1976).

A modified version of the standard wind-chill nomogram which divides the basic graph into seven comfort classes is shown in Figure 6.8. The frequency occurrence of these classes during the months of July, September, and November at Resolute and Dundas Harbour is shown in Table 6.5. The table indicates that comfort class 6 is the most severe that is likely to be encountered in the area, and that this degree of wind-chill will likely occur no more than 5 to 10% of the time, even in November. Maxwell (1980) determined that the severe conditions of classes V to VII are common in the vicinity of Lancaster Sound from December to March. Table 6.5 suggests a slight decrease in wind-chill from west to east, but the high fall winds in the proposed drilling area may offset the effect of the higher temperatures.

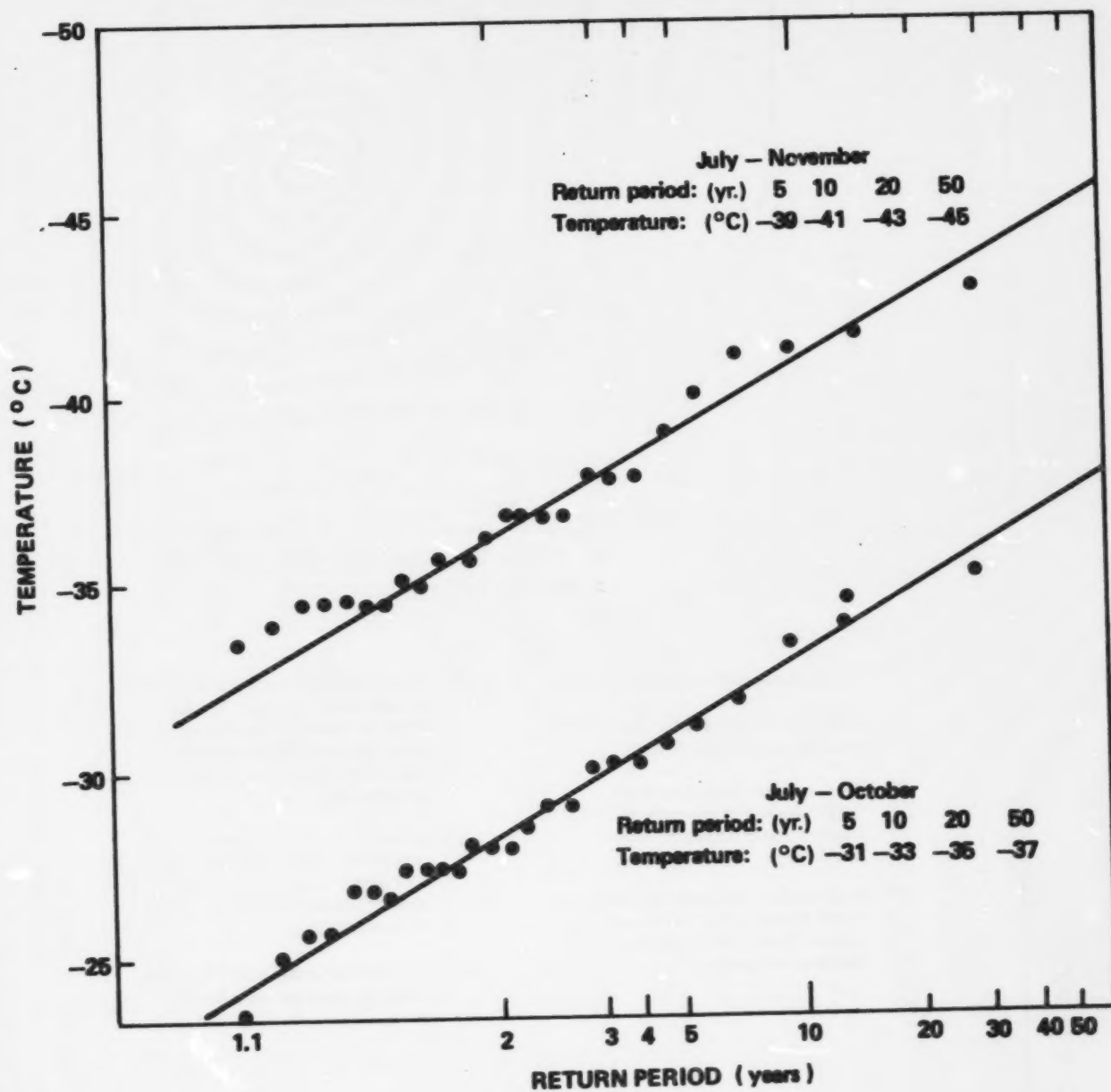
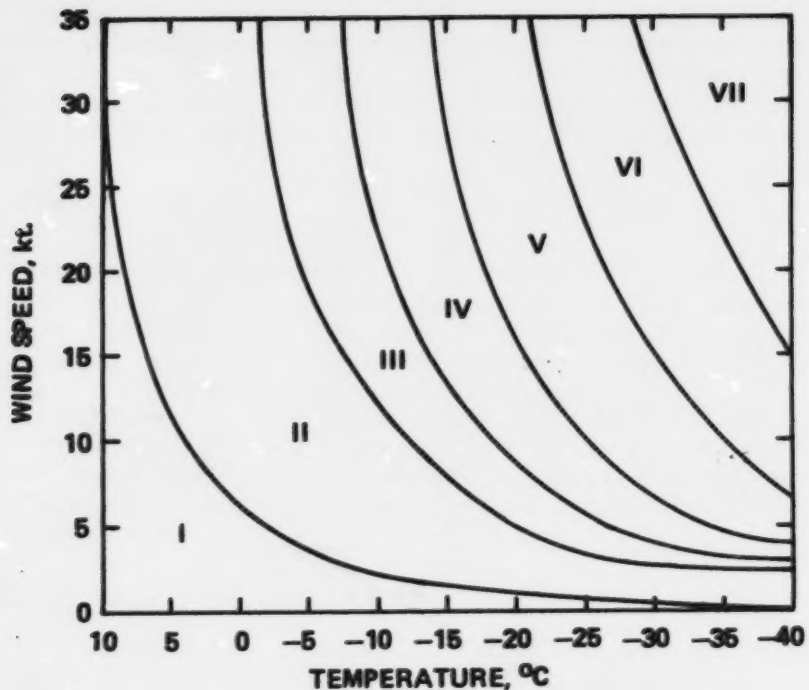


Figure 6.7 Expected extreme minimum temperatures for various return periods for Resolute A.



Comfort classes

- | | |
|--|---|
| I Comfortable with normal precaution. | V Unprotected skin can freeze in one minute with exposure. Multiple layers of clothing mandatory. Adequate face protection becomes important. Work and travel alone not advisable. |
| II Work and travel become uncomfortable unless properly clothed. | VI Adequate face protection becomes mandatory. Work and travel alone prohibited. Supervisors must control exposure times by careful work scheduling. |
| III Work and travel become more hazardous unless properly clothed. Heavy outer clothing becomes mandatory. | VII Personnel becomes easily fatigued. Buddy system and observation mandatory. |
| IV Unprotected skin will freeze with direct exposure over prolonged period. Heavy outer clothing becomes mandatory. | |

Figure 6.8 Wind-chill comfort classes based on combined wind-temperature effects.

Table 6.1 Summary of monthly mean and extreme temperature values. Bracketed figures indicate the period of record at each station.

Station	Mean Daily Temperature (°C)					Extreme High Temperature (°C)					Extreme Low Temperature (°C)				
	Jul	Aug	Sept	Oct	Nov	Jul	Aug	Sept	Oct	Nov	Jul	Aug	Sept	Oct	Nov
Arctic Bay (1938-65)	5.8	4.8	-1.6	-11.1	-21.1	23.9	18.3	13.3	6.7	2.2	-5.6	-4.4	-15.0	-32.2	-41.1
Clyde (1946-70)	4.6	4.0	-0.1	-6.6	-16.9	22.2	20.0	12.8	6.1	6.7	-5.6	-5.6	-16.1	-25.6	-35.0
Odbyur Island (1972-74)	3.9	3.1	-3.1	-10.2	-19.6	12.2	13.9	7.2	0.0	1.1	-2.2	-3.9	-15.0	-25.6	-35.6
Craig Harbour (1934-40)	5.0	3.3	-2.2	-11.1	-20.6	16.1	11.1	7.2	4.4	1.1	-1.7	-5.6	-10.6	-23.3	-35.0
Dundas Harbour (1930-33, 1945-50)	5.6	4.3	-1.0	-9.1	-15.4	17.8	17.1	11.1	2.2	2.4	-2.2	-3.1	-14.0	-23.9	-35.0
Ford Inlet (1922-60)	5.1	4.7	-1.1	-10.3	-21.2	20.0	17.2	15.6	7.2	3.9	-6.1	-3.3	-17.8	-28.9	-46.1
Resolute A (1947-70)	4.3	2.7	-4.9	-14.7	-24.2	18.3	15.0	8.9	0.0	-2.8	-2.8	-8.3	-20.6	-35.0	-42.8
Marine Grid Area #7 (1947-72)	2.9	3.2	-1.4	-4.2	-	10.0	8.9	5.6	1.6	-	-3.3	-1.7	-8.3	-12.2	-
Marine Grid Area #11 (1947-72)	4.4	3.4	0.1	-5.8	-	8.3	12.8	6.7	2.8	-	1.7	-1.7	-9.4	-15.0	-
Marine Grid Area #12 (1947-72)	3.8	3.6	-0.3	-5.2	-	8.3	11.1	6.1	1.1	-	-1.7	-1.1	-7.2	-16.7	-
Marine Grid Area #18 (1949-72)	-	3.8	-1.6	-4.3	-	-	11.1	10.0	2.2	-	-	-1.1	-3.9	-13.3	-

Source: Maxwell et al. (1980).

Table 6.2 Percentage frequency of occurrence of temperature classes during the period of record for marine grid area #11.

Temperature (°C)	Percentage Frequency			
	July	August	September	October
13.4 to 15.6		0.1		
11.2 to 13.3	0.4	0.5		
9.0 to 11.1	2.8	1.3	0.1	
6.8 to 8.9	12.1	5.6	0.1	
4.5 to 6.7	24.5	14.0	2.3	
2.3 to 4.4	38.9	39.2	11.4	0.3
0.1 to 2.2	19.0	34.8	34.3	1.4
-2.1 to 0.0	2.3	4.5	32.8	10.7
-4.3 to -2.2		*	11.8	16.8
-6.6 to -4.4			4.0	22.3
-8.8 to -6.7			1.7	19.0
-11.0 to -8.9			1.1	12.5
-13.2 to -11.1			0.4	8.0
-15.5 to -13.3				5.8
-17.7 to -15.6				2.6
-19.9 to -17.8				0.6

*Less than 0.05

Source: Maxwell et al. (1980).

Table 6.3 Percentage frequency of occurrence of temperature classes during the period of record for marine grid area #12.

Temperature (°C)	Percentage Frequency			
	July	August	September	October
9.0 to 11.1	1.1	0.9		
6.8 to 8.9	5.3	3.0		1.5
4.5 to 6.7	24.5	24.1	1.2	7.6
2.3 to 4.4	31.9	40.3	10.8	13.6
0.1 to 2.2	35.1	29.4	28.3	8.4
-2.1 to 0.0	2.1	2.3	40.8	22.0
-4.3 to -2.2			12.0	14.4
-6.6 to -4.4			5.1	14.4
-8.8 to -6.7			1.7	3.8
-11.0 to -8.9			0.3	4.5
-13.2 to -11.1				3.8
-15.5 to -13.3				1.5
-17.7 to -15.6				4.5

Source: Maxwell et al. (1980).

Table 6.4 Percentage frequency of occurrence of temperature classes during the period 1957-1966 for Resolute A.

Temperature (°C)	Percentage Frequency				
	July	August	September	October	November
13.4 to 15.6	0.1				
11.2 to 13.3	0.2				
9.0 to 11.1	1.4	0.2			
6.8 to 8.9	5.8	3.1			
4.5 to 6.7	19.8	10.7	0.2		
2.3 to 4.4	27.3	29.0	1.6		
0.1 to 2.2	35.4	34.2	6.2		
-2.1 to 0.0	9.8	17.2	17.7	0.2	
-4.3 to -2.2	0.2	5.1	22.3	2.6	0.2
-6.6 to -4.4		0.5	17.5	3.5	0.8
-8.8 to -6.7			14.0	9.0	1.8
-11.0 to -8.9			8.8	9.6	3.3
-13.2 to -11.1			6.4	12.3	3.7
-15.5 to -13.3			3.6	13.2	3.5
-17.7 to -15.6			1.3	12.6	4.4
-19.9 to -17.8			0.3	11.1	7.8
-22.1 to -20.0			*	9.3	9.8
-24.3 to -22.2				6.9	10.3
-26.6 to -24.4				4.7	15.1
-28.8 to -26.7				3.3	14.5
-31.0 to -28.9				1.3	10.8
-33.2 to -31.1				0.3	9.0
-35.5 to -33.3				0.1	3.4
-37.7 to -35.6					1.6

* Less than 0.05

Source: Maxwell et al. (1980).

Table 6.5 Percentage frequency of occurrence of wind-chill comfort classes*

Station	Month	Comfort Class						
		I	II	III	IV	V	VI	VII
Dundas Harbour	July	72	28					
	September	35	53	10	1			
	November	4	34	23	17	18	4	
Resolute A	July	42	53	2				
	September	13	58	21	7	**		
	November	3	16	19	21	26	14	1

* Comfort Classes defined in Figure 5.19.

** Less than 0.5%.

Source: Maxwell et al. (1980).

7.0 SEA STATE

Sea state is an important factor in determining the amount of time that a drillship may spend drilling, and the safety limits within which drillships and support vessels may operate. Both wind and swell waves are examined here.

7.1 WIND WAVES

7.1.1 Maxwell's Analysis

The percentage frequency of occurrence of observed significant wave heights for marine grid points for August and September is shown in Figure 7.1. Higher waves occur in September. Waves higher than 2.4 m are increasingly more frequent as one moves from Lancaster Sound (area 11) to northwestern Baffin Bay (area 12) in September.

7.1.2 Duck's Analysis

The application of the Bretschneider technique to modified Resolute winds by Duck (in Maxwell et al. 1980) and Duck et al. (1977) yielded the results shown in Figure 7.2. For a 20-year return period, the estimated extreme significant wave in northwestern Baffin Bay is 8.1 m. The corresponding extreme wave height would be 14.7 m, using a conversion of 1.8 (after Thom 1971). These values are one and one-half times those estimated for Lancaster Sound due to the greater range of potential fetches in Baffin Bay. These estimates apply at the reference points shown in Figure 1.1.

7.1.3 Thomson-Vickers' Analysis

Thomson and Vickers found that the storm that produced the highest waves occurred 25-27 September 1974. The highest computed significant wave height was 6 m. A prolonged period of southeasterly winds over Baffin Bay generated the waves. Winds in excess of 55 km/h existed for 6-12h. The maximum fetch was 840 km.

The period of the significant wave was 12 s. The peak wave height was computed to be 8 m, with a period of 13 s.

7.1.4 Lachapelle (1980)

Lachapelle found the highest significant wave at his point A to be 8.7 m and the 20-yr return period height to be 9.0 m. Maximum fetch lengths used were 1000 km.

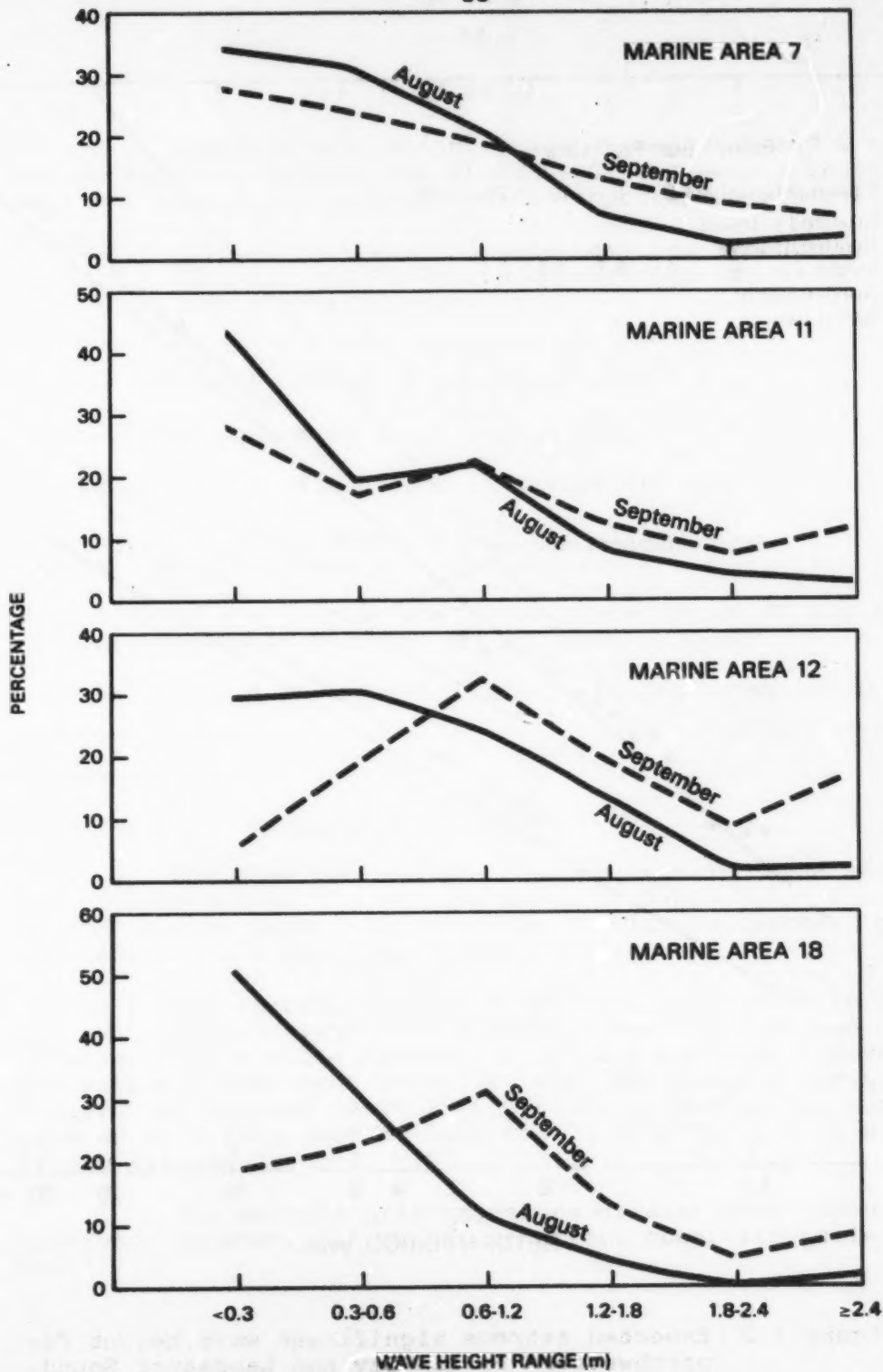


Figure 7.1 Percentage frequency of occurrence of observed wave heights for marine areas for August and September.

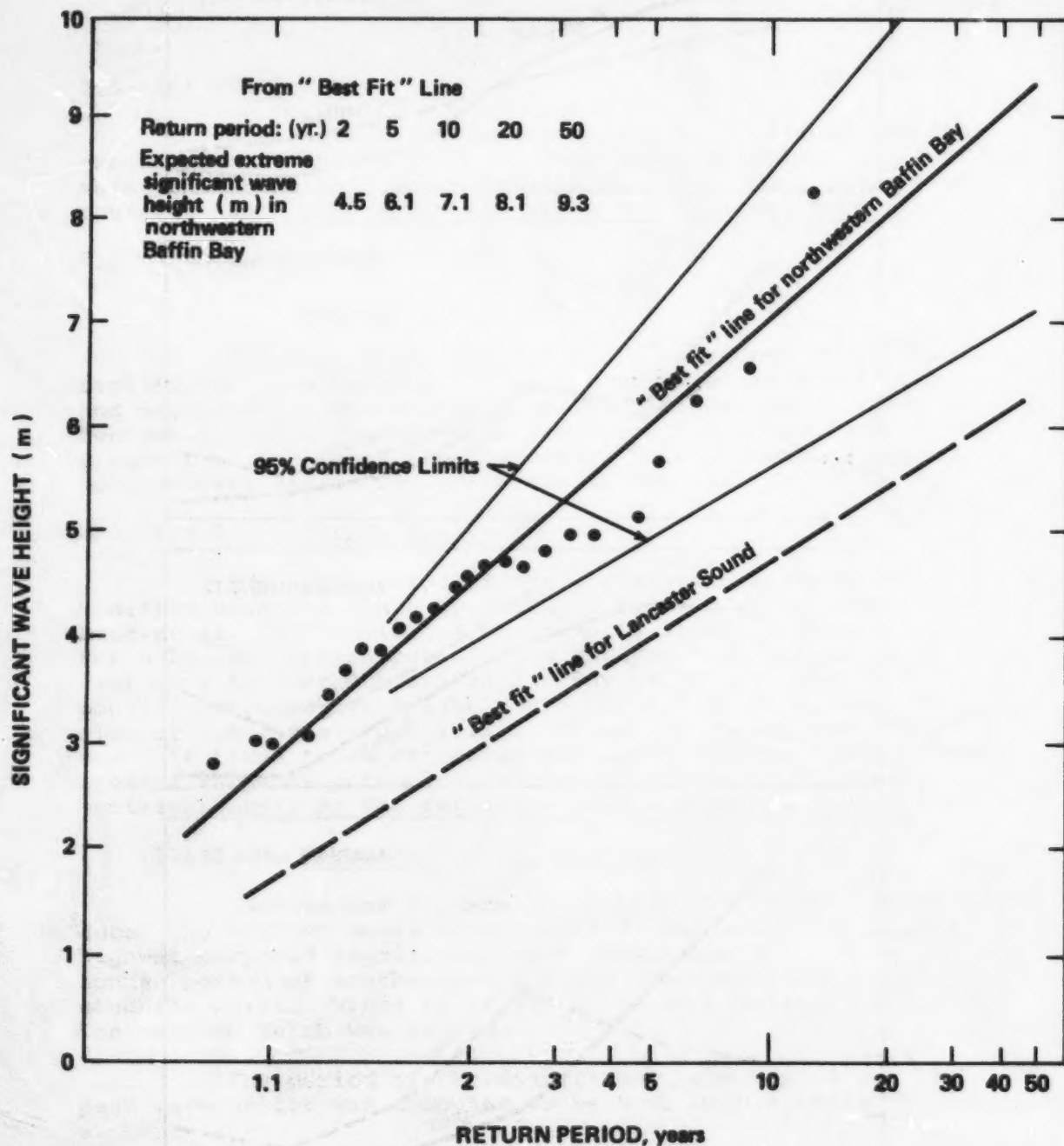


Figure 7.2 Expected extreme significant wave height for northwestern Baffin Bay and Lancaster Sound.

Computed wave heights and periods at B and C were not considered, because the winds used to generate the waves were not adequately compensated for topographic effects.

Table 7.1 Significant wave heights computed by Duck, Lachapelle, Thomson and Vickers, and observed values in north-western Baffin Bay.

Highest hindcast wave at A	8.7m
20-yr return period at A	9.0m
Highest observed wave height in marine area 12	5.8m
20-yr return period wave height calculated by Maxwell <u>et al.</u> (1980)	8.1m
Significant wave height for the severe storm on 26 September 1974 calculated by Thomson and Vickers	5.5m
Theoretical peak wave height for the 26 September storm	7.6m

Source: Lachapelle (1980).

7.1.5 Discussion

The observed and hindcast significant wave heights, in northwestern Baffin Bay are shown in Table 7.1. The method used by Lachapelle produces the largest values, but they are reasonably close to those determined by Duck.

The fetches and ice cover were determined in detail for each extreme event in the calculations by Duck and Thomson-Vickers while Lachapelle assumed that, in a given month, the extreme wind event coincided with the minimum limit of ice cover. The maximum fetch in the study by Lachapelle was 150 km greater than that used by Duck and Thomson-Vickers in studies of actual extreme events.

All methods predict values greater than those observed; however, the number of direct observations is small.

In summary, the highest significant wave height in the study area can be expected in September or in October prior to freeze-up. The 20-yr return period value of the highest significant wave is expected to be near 9 m with the extreme maximum value near 15 m, and will most likely occur in Baffin Bay. Wave heights in Lancaster Sound are lower than in northwestern Baffin Bay due to lower fetch lengths.

The Duck method probably produces the most accurate results, but the Lachapelle method is good for planning purposes because values are considered slight overestimates. Thomson and Vickers' estimates may be lower because they are derived from only a ten year period of record.

7.2 SWELL WAVES

Little information exists on swell waves in northwestern Baffin Bay and Lancaster Sound. By deductive reasoning, swells generated by storms in southern Baffin Bay and Davis Strait could be expected to reach northwestern Baffin Bay but would not likely penetrate into Lancaster Sound, due to dispersion by the surrounding land.

Marex (1973) noted that the effects of swell should not be appreciable during July and August, but would be more noticeable in September and October.

8.0 STRUCTURAL ICING

An important aspect of meteorology in cold regions is that ice may form on structures exposed to the weather. This problem is even more severe in offshore regions of the Arctic, where air temperature may drop well below the freezing point of sea water before sea-ice cover restricts marine activities. The estimation and prediction of such icing is important for dealing with the severe working conditions, mechanical complications, and decreased vessel stabilities that may be expected in late autumn. This section examines the past occurrences of extreme and severe structural icing events due to sea spray in northwestern Baffin Bay.

8.1 PROCEDURE

The results shown here are from Maxwell et al. (1980) and the procedures followed were the same as those used by Berry et al. (1975) and Duck et al. (1977). Events were selected for analysis on the basis of weather criteria set out in the nomograms produced by Mertins (1968), as shown in Figure 8.1. From these diagrams, a computer program using air temperature, sea-surface temperature, and wind velocity was developed to make linear interpolations of ice accretion rates between the boundaries of the indicated severity classes (Berry et al. 1975). For each year during the 1953-1977 period, the extreme event that contained the most hazardous conditions of wind and cold temperatures was selected from the Resolute data. In selecting the events, it was assumed that the icing season extends from the time when sea-ice cover becomes less than three-tenths concentration over 25% of the reference area at breakup until the time when three-tenths ice cover has again formed in the fall. The analysis of severe icing includes only those events for which the ice accretion rate was greater than or equal to 7.0 cm per 24 h, and includes all such events for each season from 1963 to 1974. Before ice accretion rates were determined, the Resolute wind data were adjusted to approximate conditions over water. During the calculation of ice accretion, a sea-surface temperature of 1°C was used for September events and 0°C for those occurring in October.

8.2 DISCUSSION

The results of the extreme value analysis for northwestern Baffin Bay are shown in Figure 8.2. The total amount of ice accreted for each annual extreme event is shown

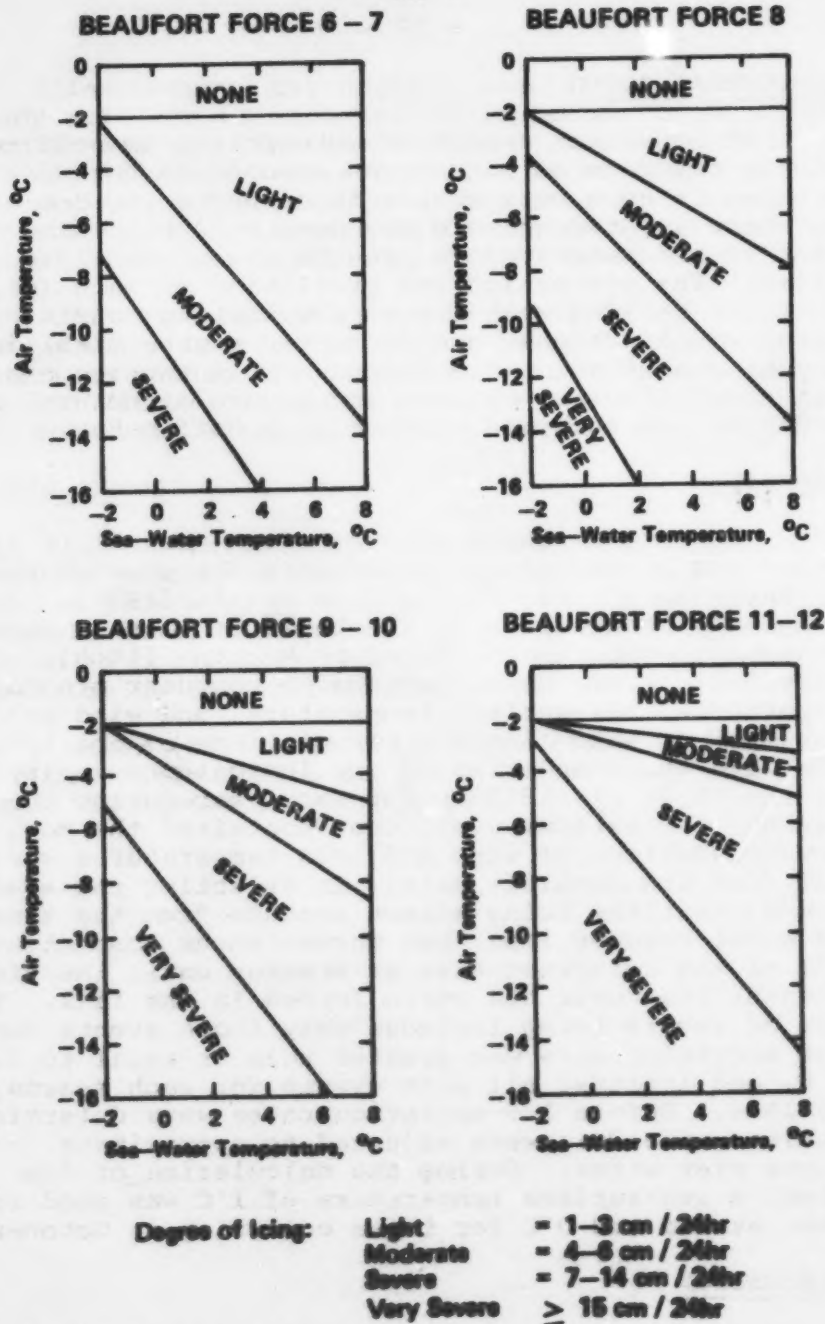


Figure 8.1 Conditions for sea spray icing.

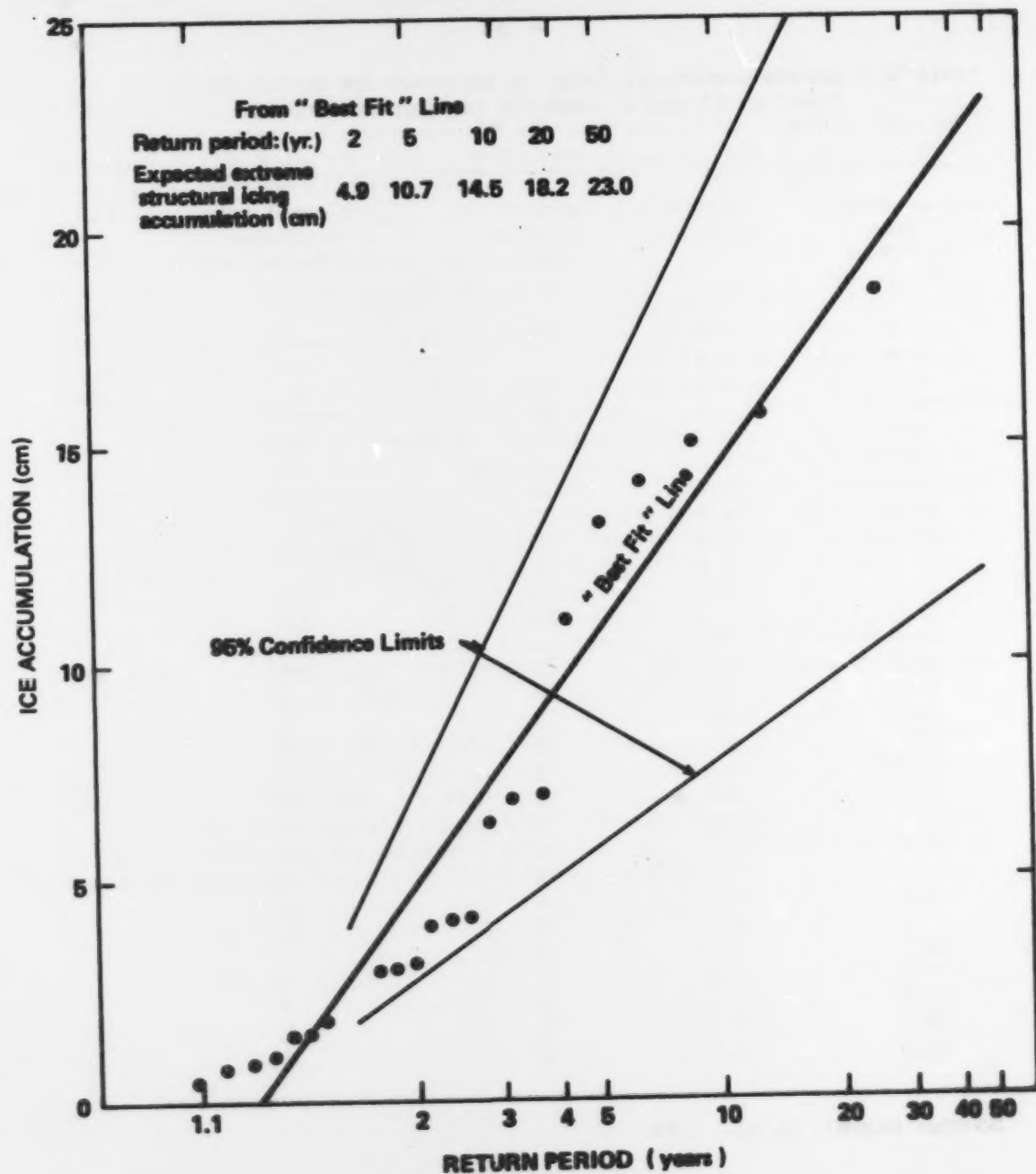


Figure 8.2 Expected extreme structural icing events for northwestern Baffin Bay.

Table 8.1 Severe structural icing in northwestern Baffin Bay based on 12 years' data for the period 1963 to 1974.

Ice accretion rate (cm/24 h)	Average duration (h)	Maximum duration (h)	Indicated rate of occurrence during 1963-74
7.0	4.5	38	374
7.5	4.4	33	347
8.0	4.3	29	316
8.5	4.3	28	293
9.0	4.3	21	268
9.5	4.2	21	263
10.0	4.2	18	242
10.5	4.1	17	215
11.0	3.8	15	190
11.5	3.6	15	171
12.0	3.4	13	146
12.5	3.3	13	130
13.0	3.1	13	108
13.5	2.9	13	89
14.0	2.7	10	78
14.5	2.3	6	55
15.0	2.1	6	47
15.5	2.1	5	41
16.0	2.0	5	34
16.5	1.8	5	29
17.0	1.7	4	19
17.5	1.5	4	15
18.0	1.5	4	15
18.5	1.3	2	10
19.0	1.5	2	6
19.5	1.3	2	4
20.0	1.5	2	3
20.5	1.0	1	1
21.0	0.0	0	0

Source: Maxwell et al. (1980)

along with the line of best fit. The extreme event in this analysis had the potential to produce 18.7 cm of ice. For a 20-yr return period, the expected extreme event is estimated to produce 18.2 cm of ice. This value is about 6 cm higher than that estimated for Lancaster Sound by Duck et al. (1977).

The results of the analysis of the severe icing events are displayed in Table 8.1. Increments of ice accretion rates are given in the first column of this table, while average and maximum durations of these rates are provided in the second and third columns. The rates in the first column must be treated as minimum values. For example, for the first increment, an ice accretion rate of at least 7.0 cm/24 h appears to have an average duration of 4.5 h. One such event, however, lasted as long as 38 h. In the same example, column four indicates that there were 374 hourly observations in the data set for which the ice accretion rate was equal to or greater than 7.0cm/24 h. Thus, the threshold for severe icing is met or exceeded 31.2 h per yr (374 divided by 12 yr), on average.

It should be noted that the information provided here does not indicate the probability of severe icing events following in close sequence.

Although structural icing caused by freezing precipitation, snow, sea fog or arctic sea smoke creates less buildup than that due to sea spray, it can be significant. For example, Rae (1951) reported that at Resolute, 9.1 mm of ice was deposited on exposed surfaces during a 24 h period of freezing precipitation in September 1948.

9.0 CLOUDS, CEILINGS AND VISIBILITY, AIRCRAFT ICING AND PRECIPITATION

Clouds, ceilings and visibility, aircraft, icing and precipitation, do not affect drilling activities directly, but may disrupt support activities by impeding aircraft and vessel movements. As a result, they are included for discussion.

9.1 CLOUD

The mean monthly sky cover for Resolute and Clyde are shown in Table 9.1. Also shown are mean monthly values for the Canadian Arctic after Huschke (1969).

Huschke concluded that the spring transition and the cloudiness of the summer season are entirely accounted for by low clouds in all arctic regions. Also, middle cloud appears quite constant year around, except for a slight maximum in October.

Thomson and Vickers (1980), studying 1978 satellite photos, found that the proposed drilling area was covered by six-to nine-tenths of low cloud or fog an average of 12 d/mo in July, August, September and the first half of October. From mid-October to the end of November broken low cloud occurred on only 8 d. This agrees with the observations in Table 9.1.

The average cloud cover increases in intensity following the peak of the heating season and reaches a maximum in September. This is caused by the increase in open water area and the air-sea temperature difference. As the season progresses, the sea becomes progressively warmer than the atmosphere, releasing more moisture that contributes to low cloud formation. The process decreases in scale following September as water becomes increasingly ice-covered.

A frequent cloud type occurring in the arctic winter and not found elsewhere is ice crystal fog. It is particularly prevalent in areas near moisture sources such as communities, animal herds and polynyas. Fraser (1973) has indicated that most clouds occurring in winter in the Arctic are composed of ice crystals.

Table 9.1 Mean monthly total cloud amounts (%)

Month	J	F	M	A	M	J	J	A	S	O	N	D
Resolute	37	41	40	47	69	74	76	79	83	74	49	39
Clyde	49	44	37	44	69	66	69	76	81	74	58	44
Canadian Arctic	45	38	44	44	60	61	67	75	78	67	50	39

Source: Meteorological Branch, Department of Transport (1970) for Resolute (1949-60) and Clyde (1942-60); and Huschke (1969) for the Canadian Arctic.

9.2 CEILINGS AND VISIBILITY

During July to early September, fog is the most prevalent cause of reduced visibilities; thereafter, snow and blowing snow become increasingly prevalent.

Two types of fog occur. From July to September, advection fog is common. This forms when air masses penetrate the region from southern Canada and are cooled from below by the underlying ice and water. Such fog is widespread during the ice-melt period, but becomes patchy later in the season, tending to be frequent and dense mainly at the edges of drifting ice. From October on, steam fog is the more frequent type formed. It is formed when very cold air passes over areas of open water. Often, it is rather localized, persisting only a few kilometres downwind from the moisture source. However, it can occasionally be more widespread, for example when cold air flows over relatively warm, large open-water areas late in the season.

Table 9.2 shows the percentage frequency of visibility by wind speed classes for the marine grid areas. There appears to be a slightly greater tendency for low visibilities (<1.8 km) to be associated with lower wind speeds than high visibilities (>9 km), as would be expected.

The percentage frequencies of occurrence of combined ceiling and visibility classes for the marine grid areas are given in Table 9.3. It should be noted that the reduced

ceiling and visibility conditions of 150 ft and/or 50 yd are more frequent in July and August than in the later months, when marine fogs occur less often and mean wind speeds are greater.

For comparison, Resolute ceiling and visibility data are given in Table 9.4. Conditions are generally worse at Resolute than in marine area 11, about the same as in marine area 12 in August and September, but better in October.

9.3 AIRCRAFT ICING

No real data are available on the occurrence of aircraft icing over the study area. However, an indication of its likelihood can be gained from the northern hemisphere aircraft icing climatology prepared by Heath and Cantrell (1972). That climatology considered only the occurrence of

Table 9.2 Relationship of visibility and wind speed in marine grid areas.

Wind Visibility Area range (nm)	Wind Speed Classes (kt)																			
	July			August			September			October										
	0-3	4-10	11-21 22+ All	0-3	4-10	11-21 22+ All	0-3	4-10	11-21 22+ All	0-3	4-10	11-21 22+ All								
07 Visib. <1	1.6	12.2	9.0	1.6	22.4	2.2	5.9	1.9	0.7	10.7	0.5	1.4	1.1	0.6	3.6	0.0	0.8	2.4	0.0	3.2
1<Visib. <5	1.0	3.2	1.6	2.1	7.9	0.4	2.6	3.4	1.6	8.0	0.8	4.1	5.0	3.5	13.4	5.7	3.3	6.5	3.2	18.7
Visib. >5	4.8	25.9	27.0	10.0	67.7	13.0	33.7	25.2	9.4	81.3	6.6	25.8	31.2	19.4	83.0	5.7	35.0	26.8	10.6	78.1
011 Visib. <1	0.9	2.3	4.2	2.8	10.2	1.7	2.3	3.3	2.1	9.5	0.7	2.0	2.0	1.5	6.2	0.3	3.2	2.4	1.6	7.5
1<Visib. <5	0.5	3.2	3.2	0.9	7.8	0.7	2.3	3.9	2.4	9.4	1.4	3.6	4.6	2.5	12.1	2.1	6.2	5.9	5.0	19.2
Visib. >5	12.0	25.3	30.4	14.3	82.0	11.1	28.7	30.5	10.8	81.1	5.7	25.4	34.6	13.9	81.7	8.5	28.8	26.1	9.9	73.3
012 Visib. <1	2.3	6.0	4.4	0.5	13.2	0.3	2.6	1.1	1.7	5.7	0.5	2.7	2.1	2.7	8.0	4.9	10.7	1.9	0.0	17.5
1<Visib. <5	0.7	3.9	5.1	2.3	12.0	0.0	3.6	4.6	2.3	10.5	1.1	9.0	5.3	9.6	25.0	2.9	1.9	2.9	0.0	7.7
Visib. >5	7.6	32.3	27.0	7.9	74.8	7.7	29.9	34.8	11.4	83.8	6.8	21.3	22.9	16.0	67.0	8.6	33.0	27.2	5.8	74.8
018 Visib. <1	Insufficient data			1.2	5.4	3.2	0.9	10.7	1.4	3.0	3.3	0.8	8.5	0.0	2.1	3.2	2.1	7.4		
1<Visib. <5	Insufficient data			1.0	5.1	6.3	0.9	13.3	1.1	4.2	7.2	3.8	16.3	0.4	5.0	10.7	7.9	24.0		
Visib. >5	Insufficient data			10.0	30.3	29.9	5.8	76.0	5.5	24.6	36.8	8.3	75.2	2.1	24.4	28.1	14.0	68.6		

Source: Marshall et al. (1980)

Table 9.3 Percentage frequency of occurrence of combined ceiling and visibility classes for the marine grid areas.

Grid area	Combined ceiling (C) and visibility (V) classes	Frequency, %			
		July	August	September	October
#7	C <1000° and/or	36.6	23.2	19.9	38.6
	V < 5 nm				
	C < 600° and/or	27.3	14.5	8.5	16.7
	V < 1 nm				
#11	C < 150° and/or	13.7	7.8	4.5	1.5
	V < 50 yd				
#12	C <1000° and/or	12.0	20.9	18.6	22.3
	V < 5 nm				
	C < 600° and/or	6.2	12.0	7.4	8.5
	V < 1 nm				
#18	C < 150° and/or	3.8	3.8	0.9	3.5
	V < 50 yd				
#12	C <1000° and/or		30.6	23.3	36.4
	V < 5 nm	insuffi-			
	C < 600° and/or	cient	20.6	9.3	19.0
	V < 1 nm	data			
#18	C < 150° and/or		10.5	3.5	6.2
	V < 50 yd				
#18	C <1000° and/or		29.1	25.4	34.0
	V < 5 nm	insuffi-			
	C < 600° and/or	cient	15.4	10.3	12.8
	V < 1 nm	data			
#18	C < 150° and/or		7.5	2.4	3.2
	V < 50 yd				

Source: Maxwell et al. (1980)

Table 9.4 Percentage frequency of occurrence of combined ceiling and visibility classes for Resolute A. Based on the period 1957-1966.

Combined Ceiling (C) and Visibility (V) Classes	Percentage Frequency				
	July	August	September	October	November
C < 1000° and/or V < 3 mi	27.1	30.1	27.9	24.0	14.1
C < 500° and/or V < 1 mi	18.8	18.8	10.0	9.0	5.2
C < 200° and/or V < 0.5 mi	10.3	7.6	4.2	3.8	1.8

Source: Maxwell et al. (1980)

Table 9.5 Probability of aircraft icing over the northwestern Baffin Bay area.

Constant pressure surface (kPa)	Corresponding mean altitude MSL (m)	Probability (P)				
		July	August	September	October	November
100	100	P 0.025	P 0.025	0.025 P 0.05	P 0.05	0.05 P 0.1
85	1400	0.025 P 0.05	P 0.05	0.1 P 0.15	0.1 P 0.15	0.05 P 0.1
70	2900	P 0.05	0.05 P 0.1	0.05 P 0.1	0.05 P 0.1	P 0.05
50	5300	0.025 P 0.05	0.025 P 0.05	P 0.025	P 0.025	P 0.025

Source: Maxwell et al. (1980).

aircraft icing, with no differentiation as to type or severity. Table 9.5, which is derived from that study, indicates the probability of encountering icing conditions over northwestern Baffin Bay at four levels of the atmosphere for each month during the July-to-November period. The values presented may be interpreted as percentage frequencies of occurrence; for example, the October probability of 0.05 for 100 kPa suggests an occurrence frequency of 5%.

Most apparent from this table is the gradual lowering of the altitude at which aircraft icing is most probable. The variation is from the 70-kPa level in July and August to 85 kPa in September and October to between 100 and 85 kPa by November. The highest probabilities (between 0.1 and 0.15) occur in September and October, at the 85-kPa level.

The icing frequencies of occurrence suggested in Table 9.5 appear to be somewhat lower than might be expected for the study area. During the fall particularly, arctic stratus and stratocumulus can be a potential icing hazard especially for helicopter operations. Because low ceilings (less than 300m) are possible up to a third of the time and because freezing can occur at low altitudes in the arctic atmosphere during the open water period, it is likely that icing could occur during a large proportion of the time that low ceilings are reported.

9.4 PRECIPITATION

The annual precipitation over the study area is approximately 200 mm, increasing along the adjacent island coasts to greater than 300 mm over eastern Devon and Ellesmere islands (see Figure 9.1). Slightly more than half of the precipitation falls during the July-to-October period. Approximately 25 mm falls during each of these months over the sea, and 50 mm per month over the islands. On average, there are 10 to 15 d with precipitation each month during the July-to-October period. On average, during July and August, most of the precipitation is rain or drizzle, but by September, about two-thirds of the monthly total is snow. In October, almost all precipitations is in the form of snow.

As a cause of superstructure icing, freezing precipitation is a potential hazard. In the study area, however, the frequency of freezing precipitation is not unusually high, amounting to between 25 and 50 h annually, over half of which occurs during September and October. In comparison, 50

to 100 h occur annually at the eastern entrance to Hudson Strait, and more than 175 h occur in the vicinity of Newfoundland each year on the average.

Offshore, in the autumn, most of the freezing precipitation is associated with frontal activity. Along adjacent island coasts, onshore wind flows from open-water areas over snow- or ice-covered surfaces can often initiate localized freezing precipitation.

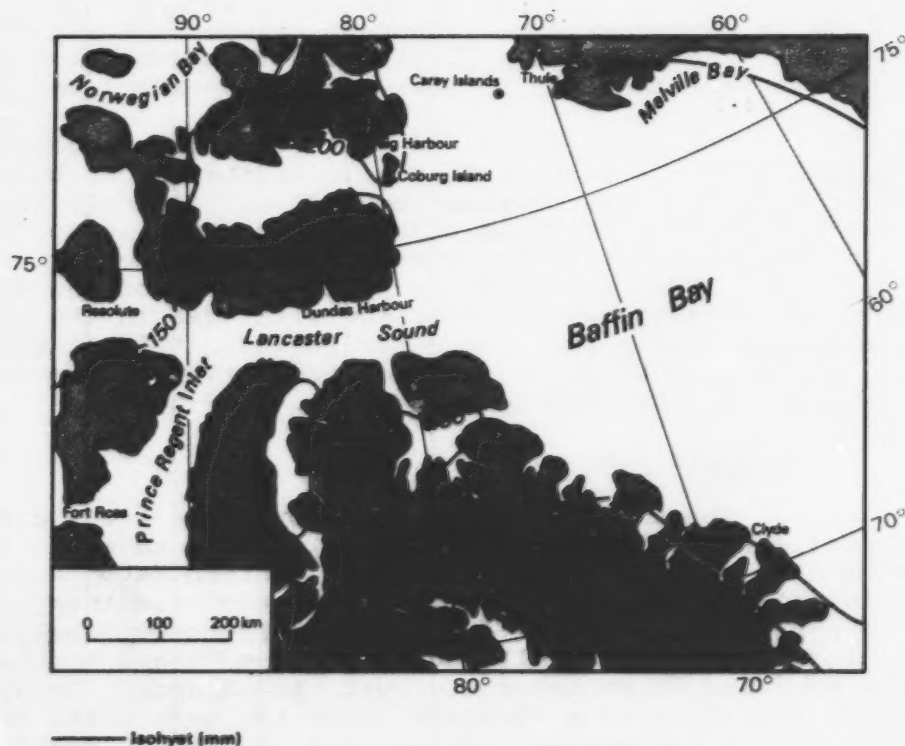


Figure 9.1 Annual mean total precipitation.

10.0 SYNOPTIC CLIMATOLOGY AND EXTREME STORMS

In this section, the synoptic climatology is described and storm types plus typical extremes are examined.

10.1 SYNOPTIC CLIMATOLOGY

Compared to other arctic areas, cyclonic activity is frequent in Baffin Bay throughout the year, and is most intense in winter. However, low pressure centres occur less than 20 % of the time during the open-water season. They normally increase in frequency and intensity as the season progresses. The preferred trajectory for most lows affecting the region is northwards through Davis Strait, and most such systems are in the occluded phase by the time they reach northwestern Baffin Bay. Occasional systems tracking north-eastward over Keewatin District or from the west along Parry Channel also occur.

The corridors frequented by low pressure centres according to Maxwell (1980) are shown in Figure 10.1. However, significant storm tracks also occur outside of these corridors. For example, the track through Parry Channel is for a storm type defined by Thomson and Vickers that is well north of the normal track. The corridor through Davis Strait to Baffin Bay is primary; the others are secondary, except that the Keewatin corridor is primary in October and November.

The topography of Baffin Island and Greenland is partly responsible for the tendency for lows to fill in Baffin Bay. For a low to maintain its depth or deepen, a well-developed 50-kPa low or trough is required. As well, an injection of cold air behind the low and warm air advection ahead of the low enhances the cyclonic circulation. This warm-cold contrast is required to supply energy to the system that maintains or deepens the low. For lows heading northwards across northern Québec, Labrador, or the Atlantic coast, this supply of warm air is physically removed by the ice cap on Greenland. Hence, without the supply of warm air ahead of it, the low fills as it moves northwards into Davis Strait and Baffin Bay. Similarly, for a low tracking north-eastwards across the Keewatin towards Baffin Island, the mountains of Baffin Island act, much like the Rockies in the west, as a physical barrier to the passage of a low. Some lows that are supported by well-developed upper troughs

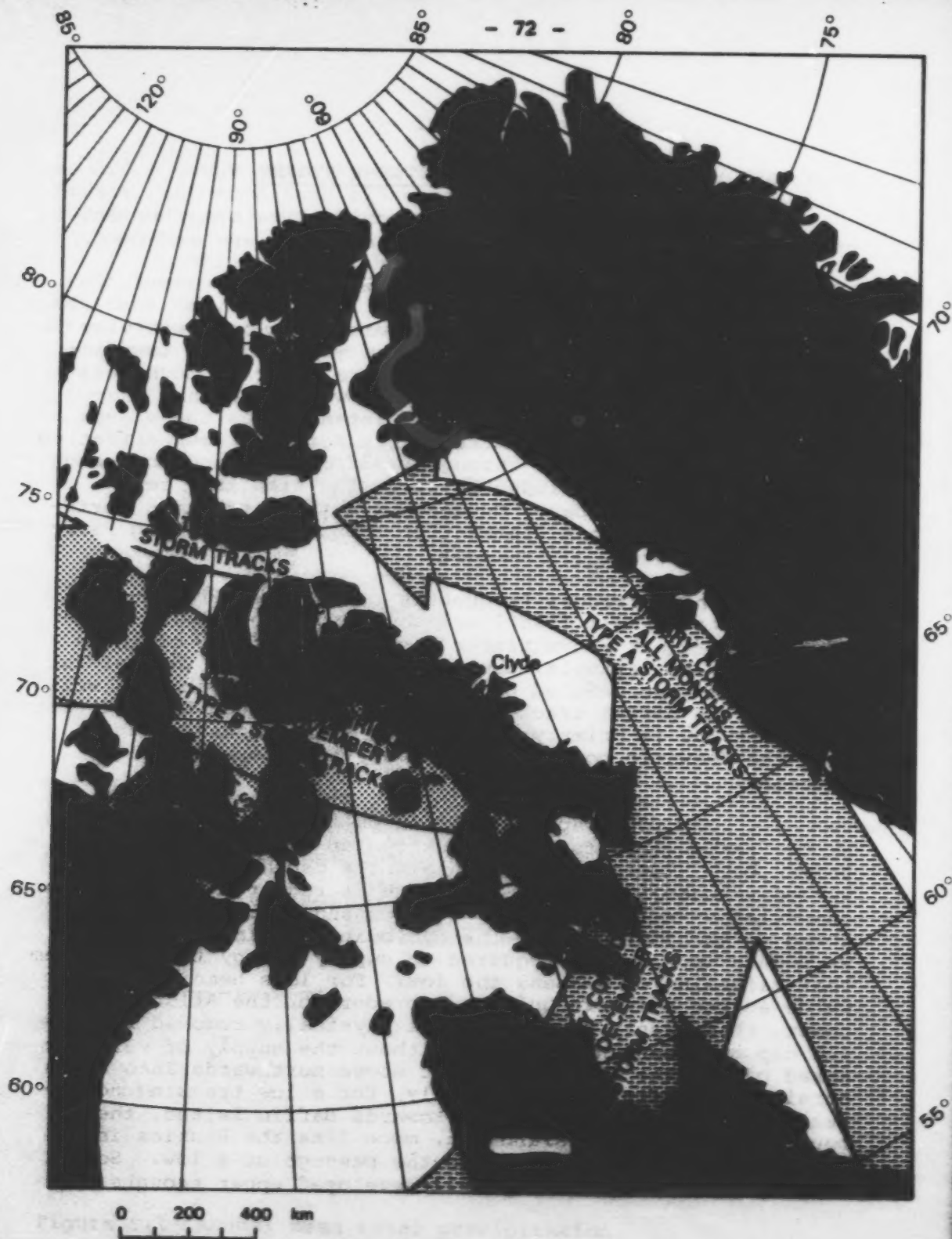


Figure 10.1 Storm track corridors affecting Baffin Bay and Lancaster Sound.

manage to cross the mountains to Baffin Bay, or to redevelop there. Once over Baffin Bay, however, the lack of good thermal contrast (at low elevations) causes the low to fill.

Thomson and Vickers (1980) define the summer and autumn seasons by the stability of the surface layer of air. In summer the air is stable; in the fall it is unstable. The transition between these seasons typically occurs in the latter half of September or early October. This model is convenient for converting geostrophic winds to surface winds and for determining low cloud and visibility conditions. However, it can be confusing because "summer" storms occur quite frequently in September and occasionally in October, months considered autumn by other accepted criteria. The seasons referred to in this chapter are according to the Thomson and Vickers criteria.

The summer season, especially July and August, has few real storms. Air temperatures are at their highest values of the year, the pressure gradient is weak in July and August but increases in September (see Figures 5.3 to 5.5), and widespread low cloud exists.

During the autumn, the frequency and intensity of cyclogenesis increases. Air temperatures decrease, ice forms over water, and the pressure gradient increases (see Figure 5.6), causing a high frequency of northwesterly winds. The incidence of low cloud decreases markedly after the water becomes ice-covered.

10.2 STORM TYPES

In their examination of storms for the 11-yr period 1969-1979, Thomson and Vickers found four storm types which met their selection criteria of 65 km/h for a minimum 6 h duration during the period July 1 to November 30. These storms were labelled as types A, B, C and D and are described below.

10.2.1 Type A Storms

A typical type A storm is one that moves up the Davis Strait corridor (Figure 10.1) to the Brevoort Island area off southern Baffin Island. The surface low may fill there, leaving a trough northward along the west Greenland coast and creating northwesterly winds in western Baffin Bay. An example is shown in Figure 10.2. Usually the trough eventually crosses Greenland to develop a new surface low off the east coast.

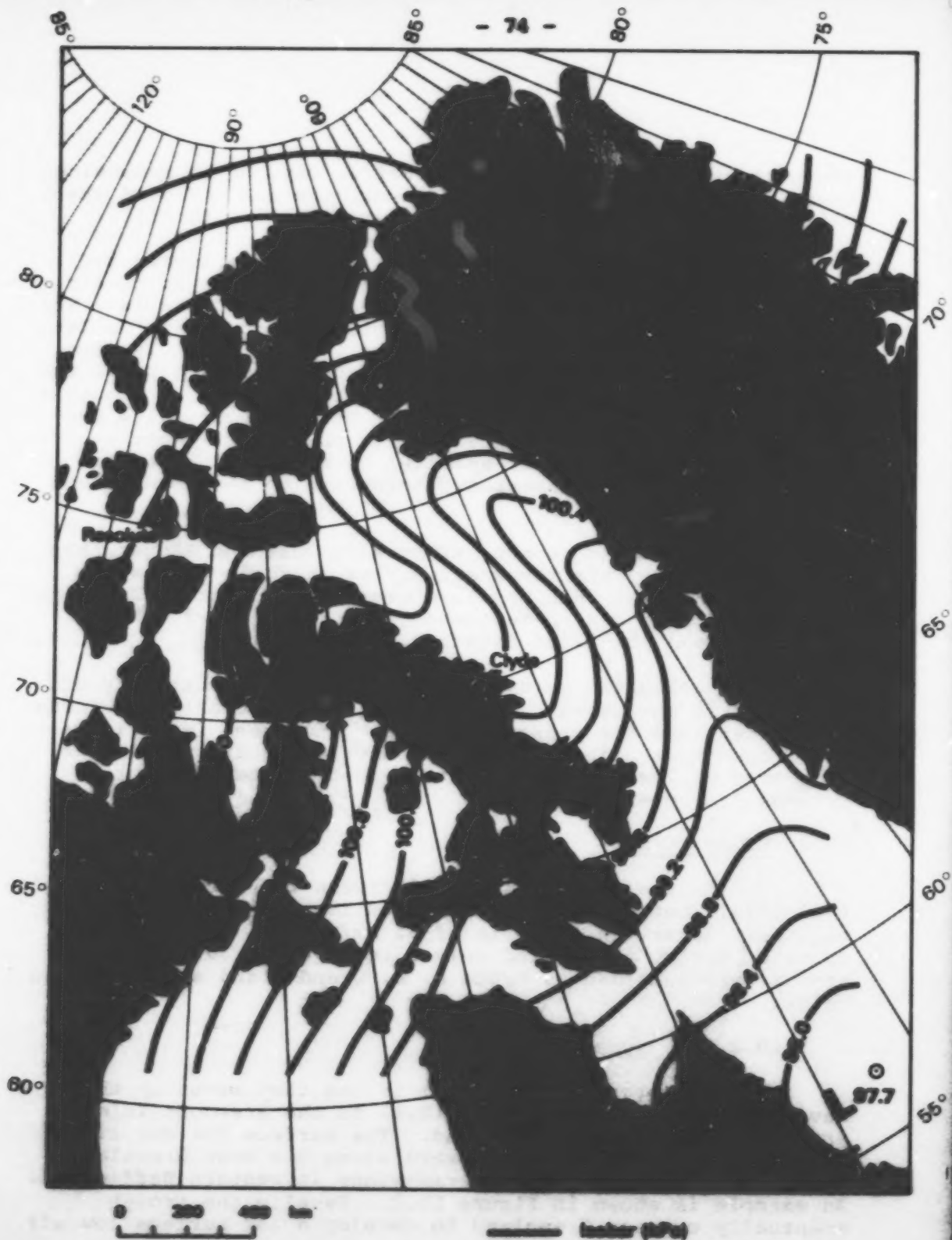


Figure 10.2 Mean sea level pressure pattern for 1200 GMT, 23 November 1976, showing a Type A storm development.

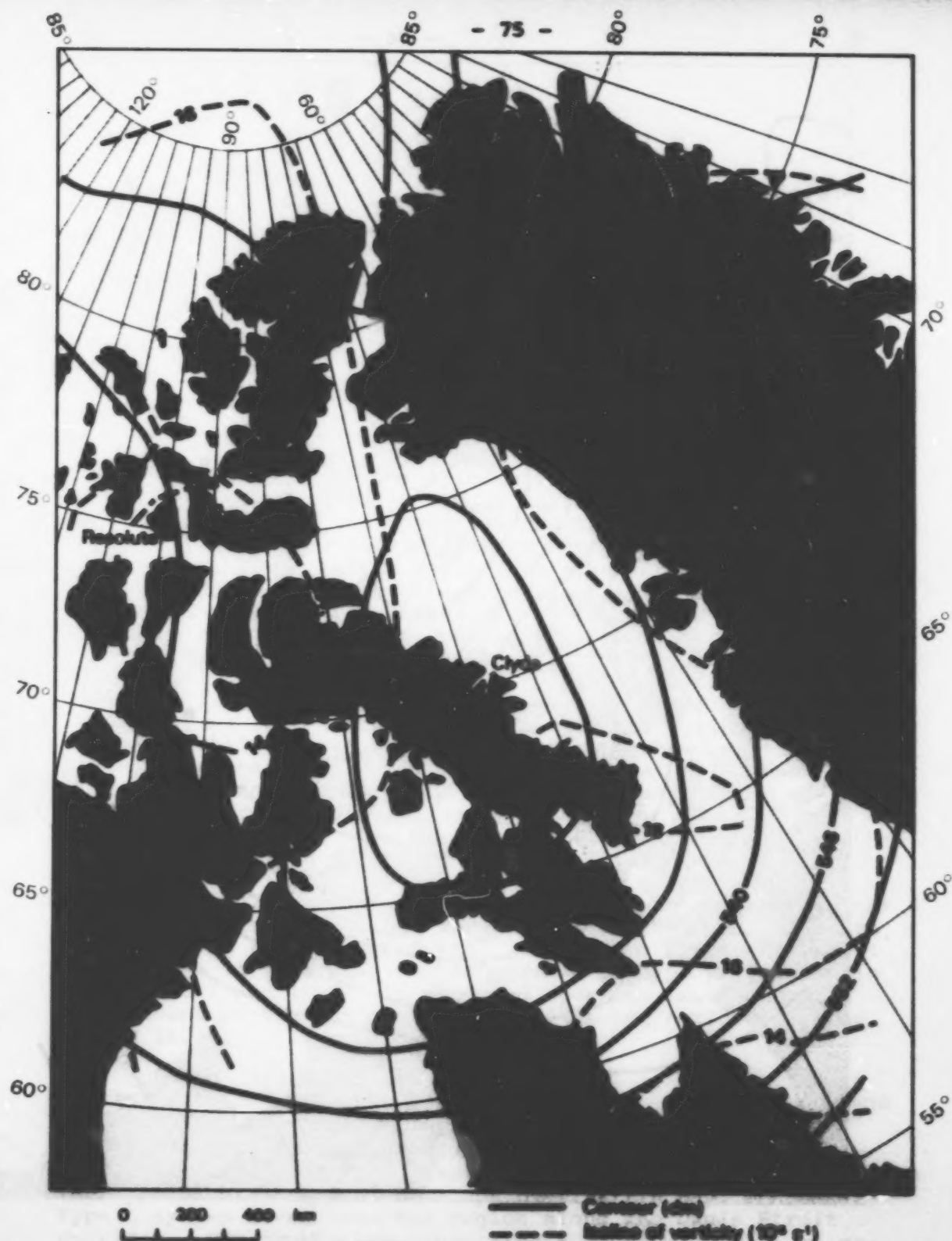


Figure 10.3 50 hPa contour pattern for 1200 GMT, 21 August 1978, associated with a Type 3 storm development.

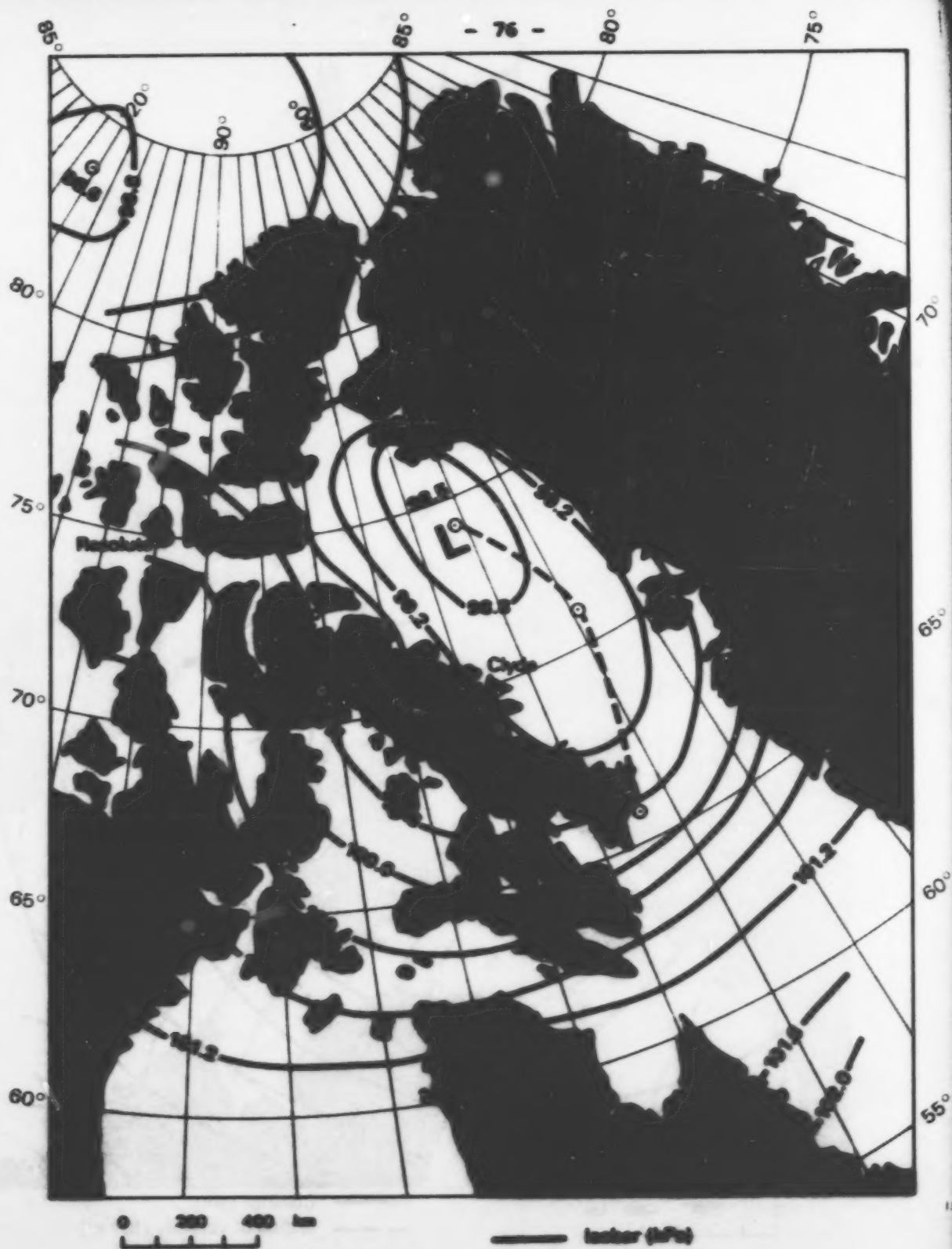


Figure 10.4 Mean sea level pressure pattern for 1800 GMT, 21 August 1978, showing a Type A storm in Baffin Bay.

Occasionally, however, the low centre will develop in the west Greenland trough and move northward into Baffin Bay to produce strong northwest winds in western Baffin Bay. An example of the associated upper level flow is shown in Figure 10.3 and the subsequent surface storm is shown in Figure 10.4. This latter development was the most severe Type A storm in the 1974-1978 period studied by Thomson and Vickers in Maxwell *et al.* (1980). Type A is most common in the region.

10.2.2 Type B Storms

This storm type occurs in the storm track corridor over the Keewatin District (Figure 10.1). It always has a 50 kPa low or trough and a strong surface high pressure area over Greenland. As the upper low tracks northeastward over Keewatin, falling surface pressures often increase the pressure gradient over Baffin Bay. This often creates strong southeast winds in northwestern Baffin Bay and east winds in Lancaster Sound. Surface lows may be associated with the upper centre over Keewatin, but this is not a necessary condition for development of the strong winds in the study area. An example of Type B that has an associated surface centre is shown in Figures 10.5 and 10.6. This storm type creates the highest waves in the study area if it occurs during the period of maximum open water. The example shown was one of the most intense in the 11 yr period examined by Thomson and Vickers. A destructive storm that caused much damage at Dundas Harbour 29 June 1927 was Type B.

10.2.3 Type C Storms

The Type C storm usually travels eastward across the Queen Elizabeth Islands through Lancaster Sound, or south of these. It is associated with the secondary west-to-east-track shown in Figure 10.1. An example of Type C is shown in Figures 10.7 and 10.8. It produced moderate southeasterly winds ahead of the surface centre and strong northwesterlies behind it.

10.2.4 Type D Storms

The Type D storm creates the same environmental effects as Type A, and some surface lows of either types may look identical, once they develop. The difference is that the Type D surface storm develops over Baffin Bay, whereas a Type A system moves into the region along the Davis Strait corridor. The 50 kPa low supporting a Type D storm is gener-

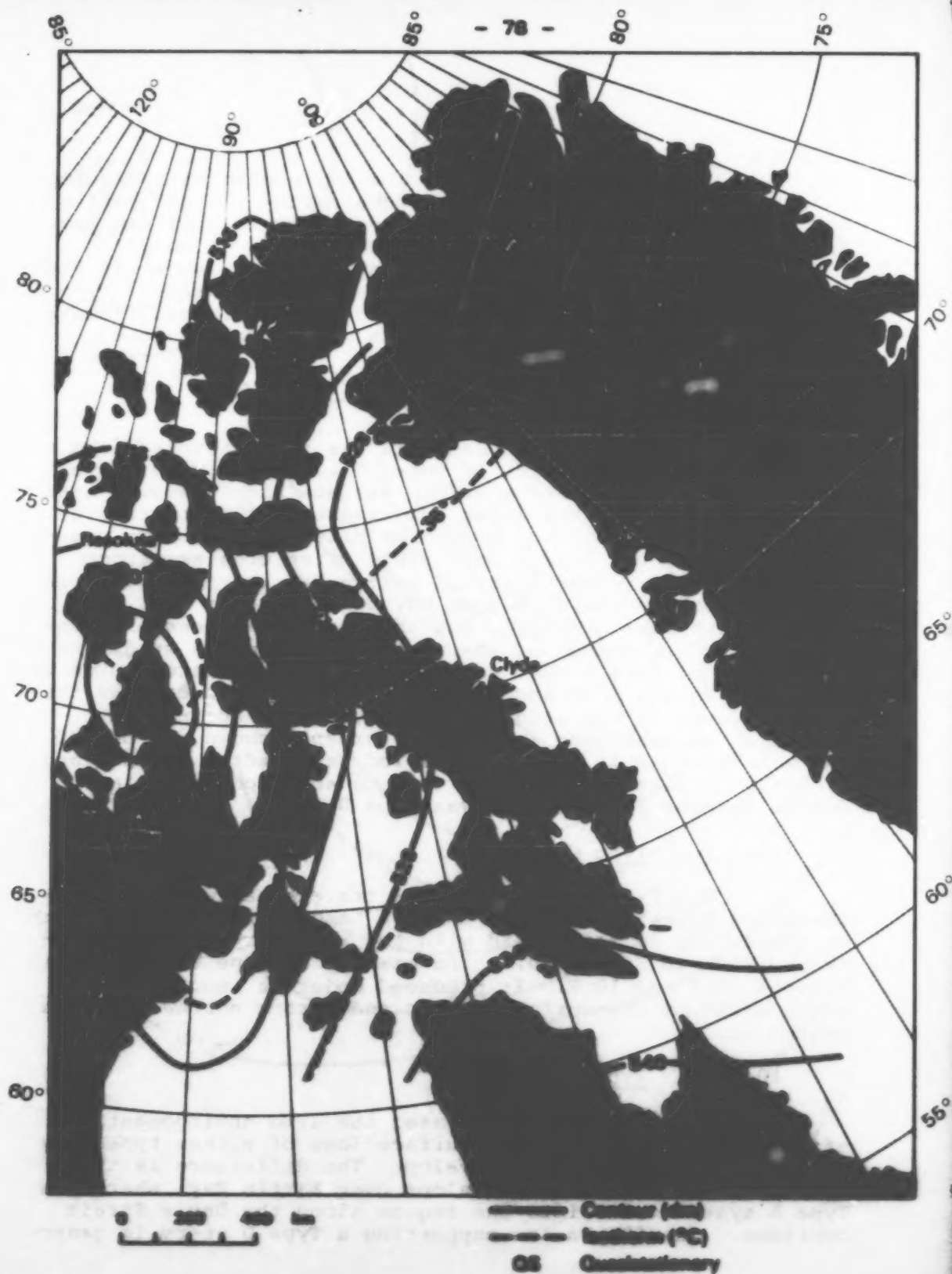


Figure 10.5 50 hPa contour pattern for 0000 GMT, 25 September 1974, associated with a Type B storm development.

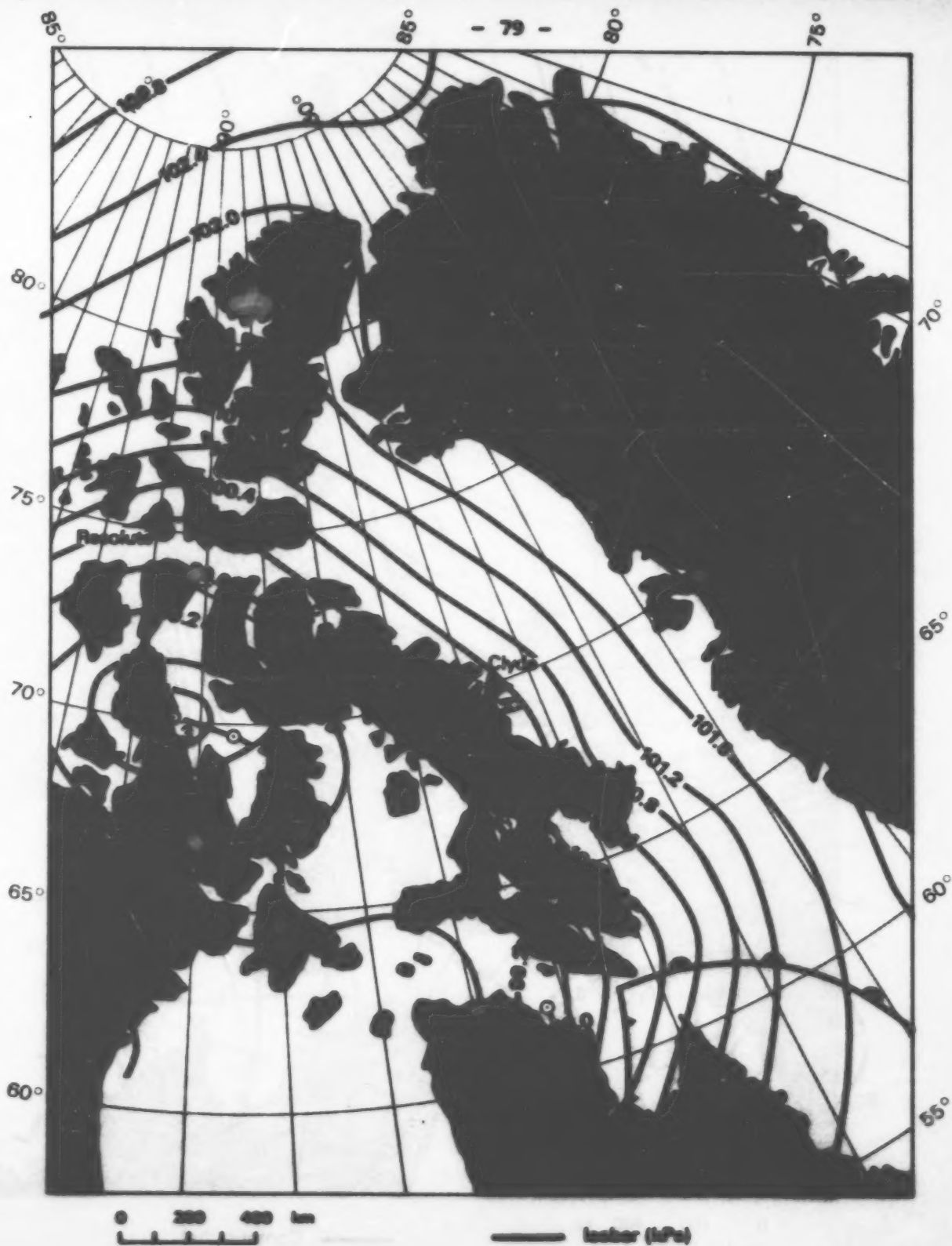


Figure 10.6 Mean sea level pressure pattern for 0000 GMT, 26 September 1974, showing a Type 2 storm centre over British Peninsula.

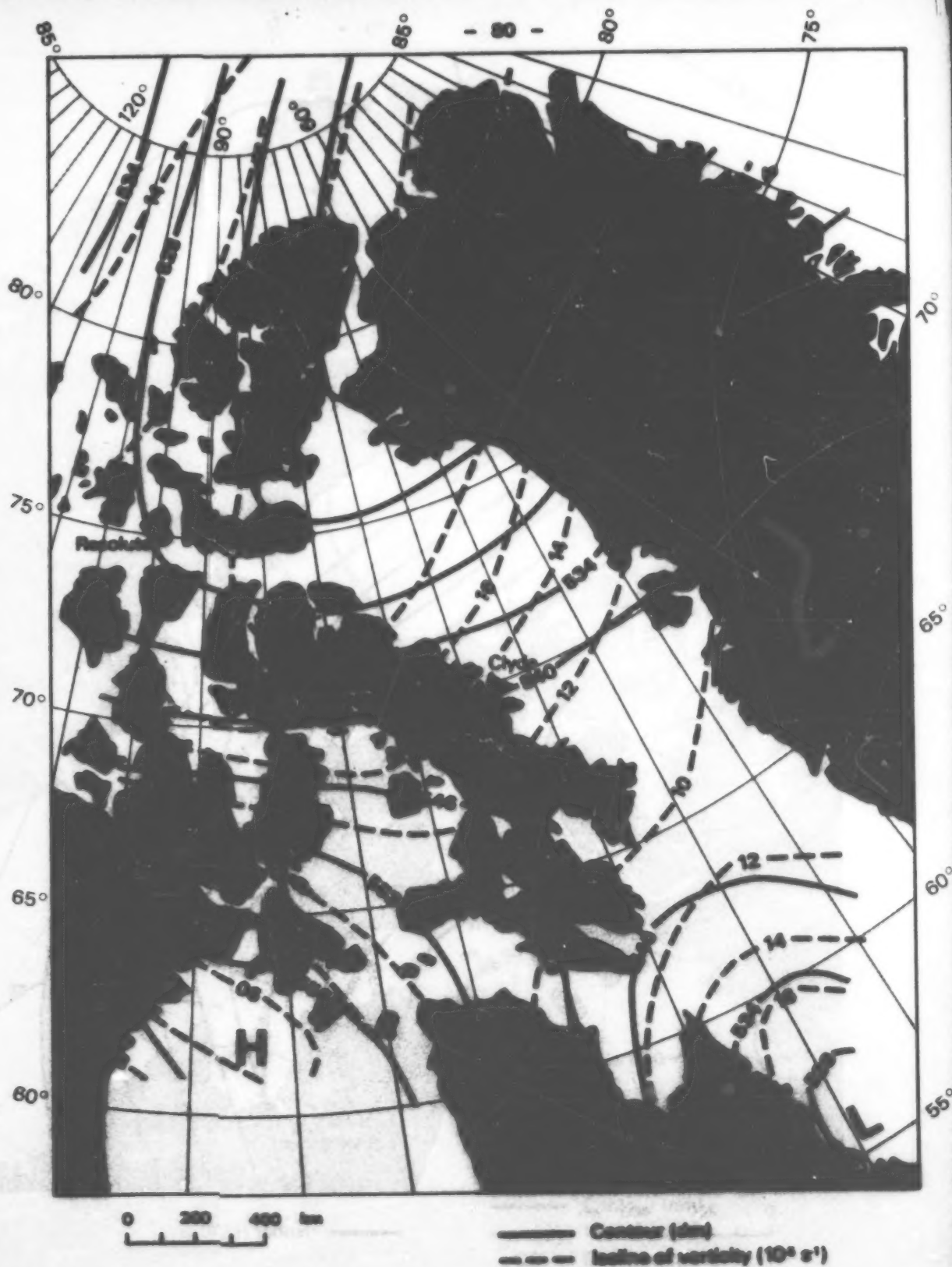


Figure 10.7 50 mb contour pattern for 0000 GMT, 15 September 1978, associated with a Type C storm.

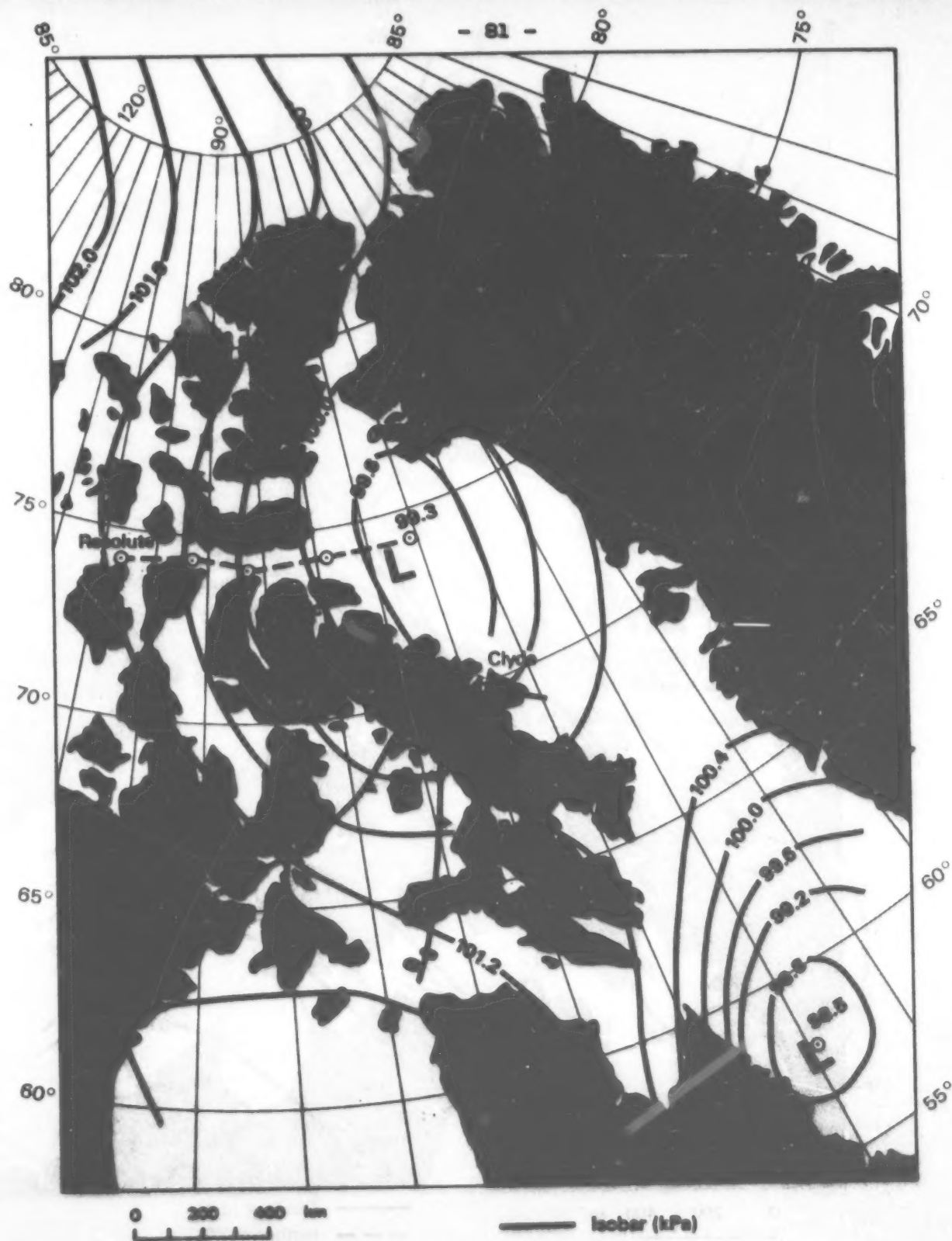


**Figure 10.6 Mean sea level pressure pattern for 0000 GMT,
18 September 1978, showing a Type C storm.**

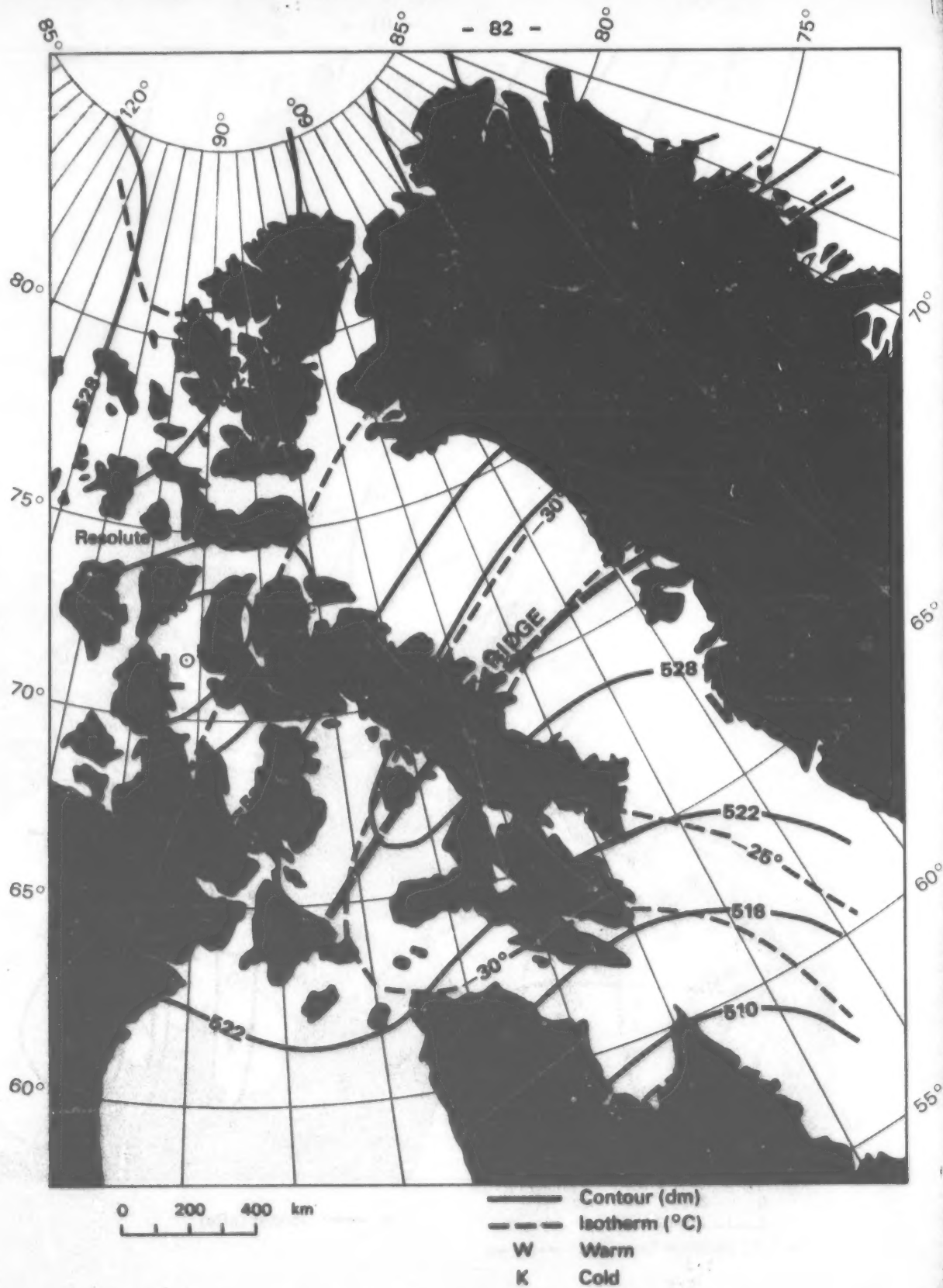


Figure 10.9 50 kPa contour pattern for 1200 GMT, 23 November 1976, associated with a Type D storm development.

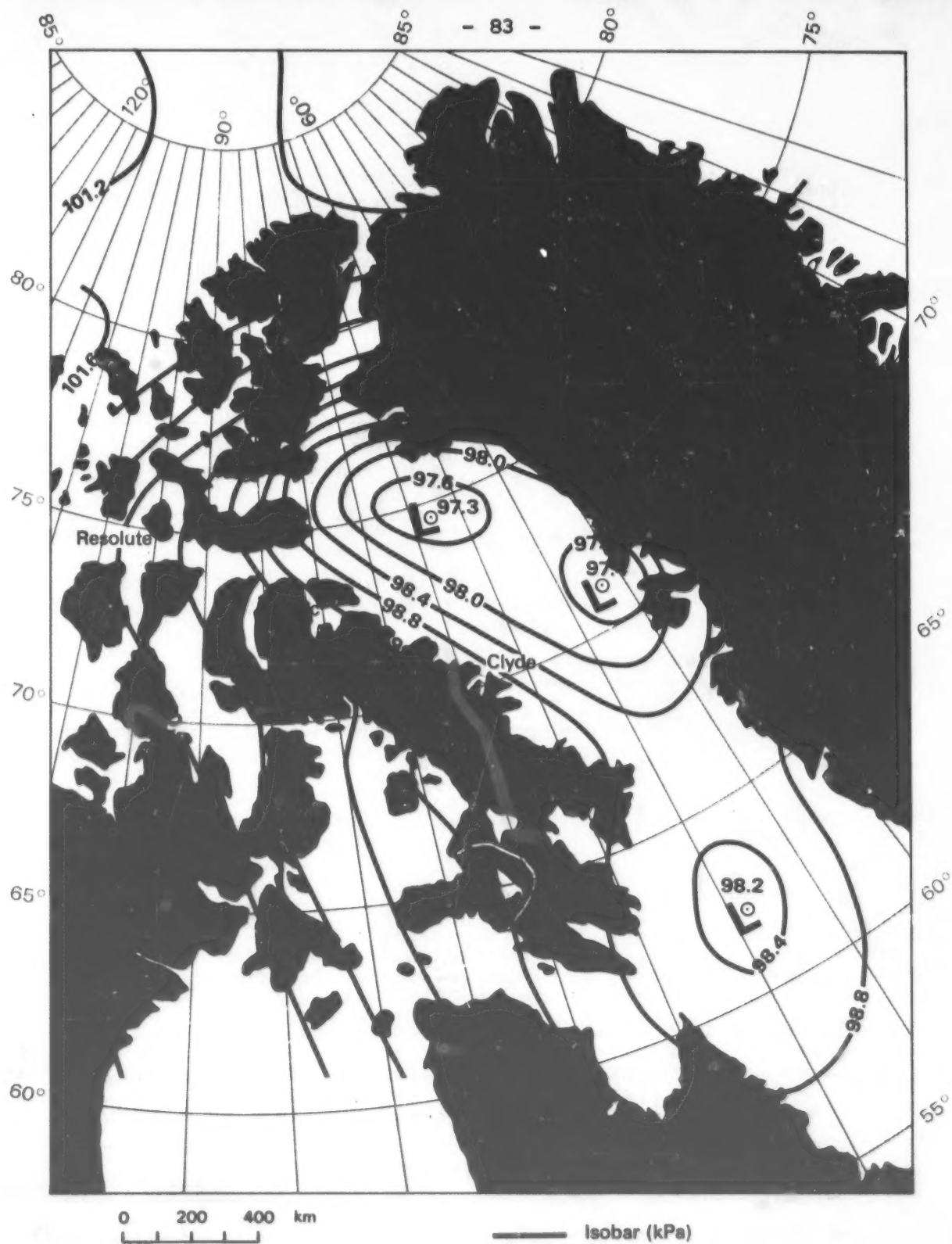


Figure 10.10 Mean sea level pressure pattern for 1800 GMT, 24 November 1976, showing a Type D storm centre in Baffin Bay.

ally centered over Boethia Peninsula with a southwesterly flow across the mountainous terrain of northern Baffin and Bylot islands, which causes lee cyclogenesis in Baffin Bay. The example of this type, shown in Figures 10.9 and 10.10, created the most severe weather conditions in the 11-year period studied by Thomson and Vickers. It is the only one that occurred in that period; however, it was preceded by a Type A development.

10.3 FREQUENCY

The intensity and frequency of the storms increases as the season progresses and the most intense storms occur in November. Table 10.1 shows the percentage frequency of occurrence of the four storm types by season, and total storms by month. Peak winds and the duration of storm conditions for each type are also given.

Table 10.1 Frequency, intensity and duration of storm types in the 1969-1979 period. Source: Thomson and Vickers (1980).

Type	Number of storms (%)	Peak wind, km/h	Duration (h)		
			Average	Shortest	Longest
1. Summer storms (23 occurrences)					
A	10(43)	340/90	13	6	24
B	8(35)	150/72	22	18	30
C	5(22)	220/96	15	6	36
D	-	-	-	-	-
2. Autumn storms (58 occurrences)					
A	36(62)	330/128	21	6	90
B	15(26)	120/142	20	6	42
C	6(10)	020/94	24	6	54
D	1(2)	325/125	30	30	30
3. Storms in both seasons (81 occurrences)					
A	46(57)	330/128	17	6	90
B	23(28)	120/142	21	6	42
C	11(14)	220/96	20	6	54
D	1(1)	325/125	30	30	30
4. Storm total by monthly occurrence					
Month	July & August	September	October	November	
Occurrences	10	15	27	29	

Meteorological conditions over the 11 years were seldom severe enough in July and August to reach storm conditions. Storms occurred in this period in northwestern Baffin Bay only 10 times, or on average, less than once per season. Southeasterly and northwesterly gales are equally likely. Type B storms occur almost as frequently as Type A in the summer, but significantly less frequently than Type A in the autumn. Type B storms cause the highest waves because the greatest fetch can occur with southeast winds.

The frequency and intensity of storms increase in September; on average, there is one storm per season in September. Two or three storms per year occur in each of October and November. In October, one storm can be expected to have winds that reach at least 90 km/h, while in November one storm per season is likely to have winds in excess of 100 km/h. The October storms are most significant if they occur prior to freeze-up when the potential development of waves, freezing spray and aircraft icing is greatest.

10.4 EXTREME STORMS

Two storms that had the most severe weather and wave conditions in the summer-autumn seasons of 1969-79 were examined by Thomson and Vickers (1980) to depict severe environmental conditions that could be encountered in northwestern Baffin Bay. For comparison, some estimated extreme conditions in other regions are shown in Table 10.2.

Although prevailing winds in the region are from the northwest and storms with prolonged severe northwest winds are the norm, storms with easterly winds, although less frequent, can be just as severe or more severe than the former. (Fraser 1973; Thomson and Vickers 1980).

Table 10.2 Comparison of estimated extreme storm conditions in northwest Baffin Bay with other regions. Values are extremes with a 25-yr return period. Source: k et Duc al. (1977) and Maxwell et al. (1980).

Region	Hourly wind speed (km/h)	Significant wave height (m)	Amount of ice accretion (cm/24 h)
Northwestern Baffin Bay	106*	8.4*	19

* Wind and wave values are annual except for northwestern Baffin Bay, Lancaster Sound and the Beaufort Sea, where the values apply to the open-water season only.

Table 10.2 Cont.d

Region	Hourly wind speed (km/h)	Significant wave height (m)	Amount of ice accretion (cm/24 h)
Lancaster Sound	109	5.8	13
Beaufort Sea	113	6.5	28 to 39
Gulf of Alaska	169	15.5	N/A
Southern Newfoundland waters	171	18.0	N/A
Southern California coast	113	11.6	N/A
Gulf of Mexico	156	13.8	N/A

10.4.1 Extreme storm: 23-25 November 1976 (Type A and D)

The most severe winds associated with fall storms occur in November. However, there are no waves or structural icing hazards because the area is ice-covered.

As a Labrador low moved northeastward on 23 November, a sharp trough developed along the west Greenland coast into Baffin Bay. Northwesterly gales developed over northwestern Baffin Bay near 1200 GMT, 23 November. The Labrador low moved east of Greenland, but the west Greenland trough remained strong. This was a typical type A development shown in Figure 10.2.

However, on 24 November, the 50 kPa low over Boothia Peninsula (Figure 10.9) initiated a Type D development in the already strong West Greenland trough, which resulted in the intense surface low shown in Figure 10.10. It produced 100 km/h winds for approximately 12 h. Winds began to diminish after 0000 GMT, 25 November.

10.4.1.1 Meteorological extremes

The following paragraph describes extremes that would likely be associated with storms such as that of 23-25 November 1976. Steady winds of 74 km/h and air temperatures of -20°C would create a cooling rate of 2400 W/m^2 (comfort class VI in Figure 6.8). These extremely cold conditions

would cause exposed flesh to freeze within one minute, so considerable protection and carefully controlled work schedules would be required for those engaged in outdoor activity. Flying weather could be adversely affected due to low visibility and "whiteout" in blizzard conditions. Also arctic sea smoke and low cloud downstream from leads or polynyas could cause local low ceilings and visibilities.

10.4.2 Extreme storm: 25-27 September 1974 (Type B)

This Type B storm was one of the most intense in the 11-yr period studied. It occurred when Baffin Bay was ice-free, allowing waves to build over an 840 km fetch.

The synoptic pattern of the storm is shown in Figures 10.5 and 10.6. Strong southeasterlies prevailed ahead of this centre on 25 and 26 September. As a low developed near Clyde by 0000 GMT on 27 September and moved northwestward, one ship in the northwest quadrant of the low reported northeast winds of 100 km/h. The storm centre moved northwest and filled on the 27 September.

10.4.2.1 Meteorological extremes

This system produced winds in excess of 55 km/h for 30 h. Southeast winds greater than 70 km/h occurred for 6-12 h and one ship reported storm force winds. Waves reached significant wave heights of 6 m and a peak of 8 m.

The sea surface temperature was 0°C and the air temperature was -1°C, so no freezing spray was reported. If, however, the air temperature had been 2°C lower, severe structural icing could have occurred. Temperatures did fall near the end of the storm, but winds were also decreasing.

Visibilities were generally good throughout the storm, although snowflurries frequently lowered visibilities to 8 km. Along the Baffin Island coastline and in Lancaster Sound, snowflurries reduced visibility to 5-10 km with one report of 1 km in snow.

The wind chill was 1375 W/m^2 , increasing to 1475 W/m^2 due to decreasing temperatures. These are in comfort class II in Figure 6.8.

11.0 POTENTIAL FOR AIR POLLUTION AND CLIMATIC CHANGE

11.1 AIR POLLUTION POTENTIAL

Parameters that give an indication of air pollution potential are: air temperature inversion frequency, calm-to-light wind occurrence and ventilation coefficients. Resolute and regional data were studied by Maxwell et al. (1980) and results indicate that northwestern Baffin Bay is very pollution prone during the summer and fall. Ventilation coefficients, a measure of the atmosphere's ability to disperse pollutants, are near 2000 m²/s in July and August and between 1000 and 1500 m²/s during September and November. Values above 6000 m²/s indicate low air pollution potential.

11.2 CLIMATIC CHANGE

Data used in various studies reported here are based on observations taken mainly in the last 30 years. The validity of the results of studies and their relevance to events over the remainder of this century depends on possible climatic variations in the future. If these variations are small, then the findings of the studies herein reported will be significantly representative of the next 30 years.

Climatic warming in the future, mainly due to increased CO₂ levels in the atmosphere, appears to be the greatest concern at present.

There are a number of opposite views. For example, Dunbar (1976) suggests that natural events like the violent Krakatoa eruption of 1883 will likely override competition from man-made influences. Recently, Koerner and Fisher (1979) have suggested the alternative possibility that climatic cooling may extend into the next century, based on their analysis of ice cores from several locations in the arctic islands. Bradley (1973), in a review of seasonal climatic fluctuations on Baffin Island, concluded that a significant variation occurred in the sixties, with warmer winters and higher precipitation but cooler summer temperatures. The net result was an increase in glaciation in the region.

The relationship between temperature fluctuations and ice conditions is not always one-to-one. Jacobs et al. (1979) studied recent year-to-year variations in seasonal temperatures and sea ice conditions in the eastern Arctic,

and concluded that ice conditions in Baffin Bay do not correlate well with regional temperature variations. Synoptic events and their resulting winds seem to create more variation in sea conditions in Baffin Bay than does regional temperature.

Episodes of both cooling and warming will continue to occur in the short term. Atmospheric scientists suggest that there is a likelihood that significantly warmer conditions will prevail in the Arctic, beginning in the first half of the next century. This could lengthen the drilling season in November, which is the peak storm period in the fall. Although in the last 30 years, November is the most intense storm period, peak storm conditions may shift to December if the climatic summer season lengthened.

Climatic prediction has no proven skill, but Maxwell et al. (1980) conclude that the best existing information indicates a long-term warming trend. The trend is expected to be so gradual that there will be no significant changes in the synoptic and sea ice regimes for at least 15 years. Shorter term trends could produce periods of cooler or warmer conditions.

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